G.E.C. Journal

VOL. III. FEBRUARY, 1932. No. 1.

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Published by

THE GENERAL ELECTRIC Co., LTD.
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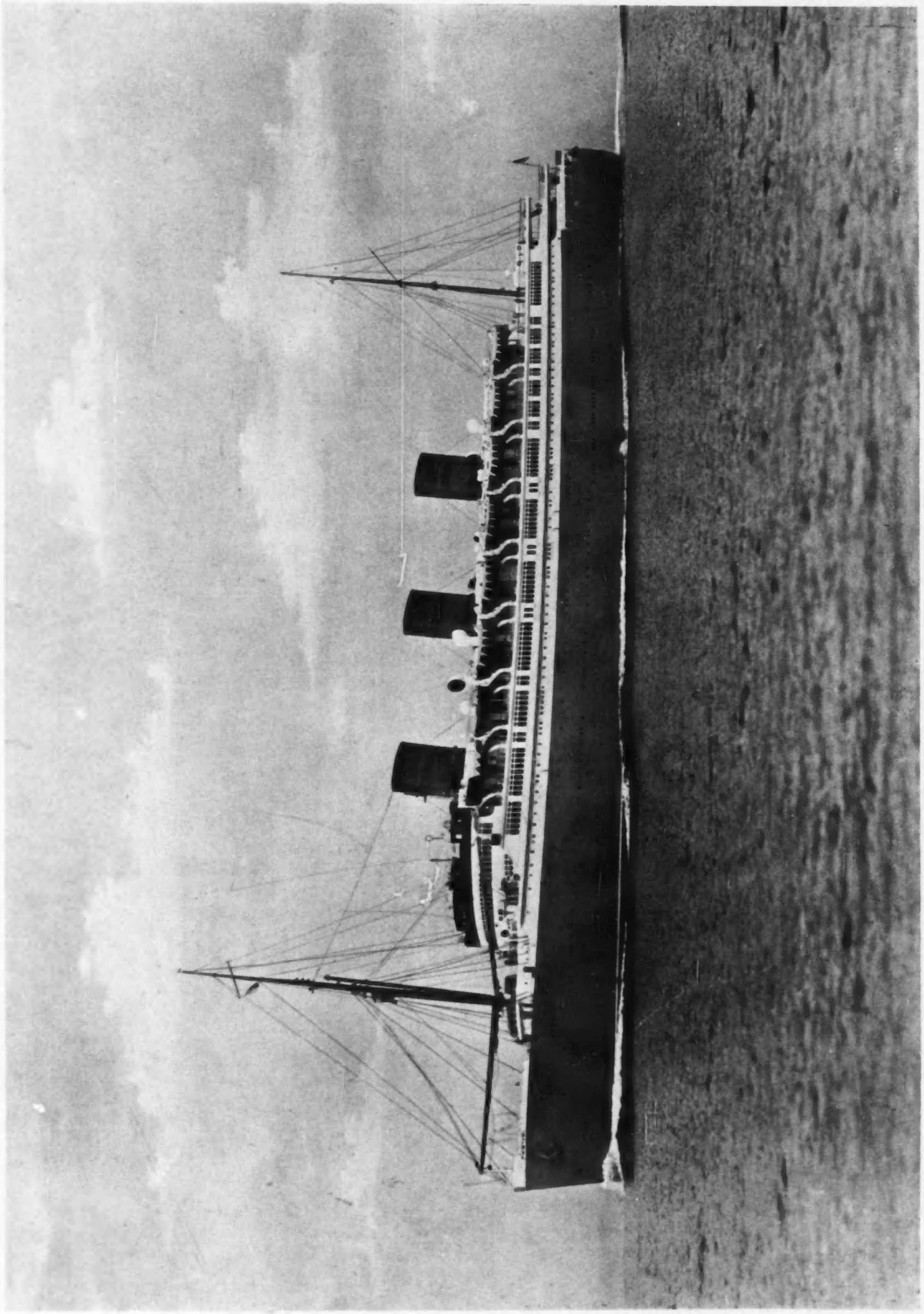

THE Q.T.E.V. "MONARCH OF BERMUDA."

G.E.C. Journal

VOL. III. FEBRUARY, 1932. No. 1.

Electrical Progress and Development during 1931.

By H. W. RICHARDSON, B.Sc., M.I.E.E.
Editor of the "G.E.C. Journal."

THE year 1931 has been dominated largely by events of great political and financial moment. Such crises inevitably hamper industry. But the determination shown in facing the issues at stake is the best guarantee that industry will be given a fair chance of revival.

Electrically speaking, the most prominent happenings of the past twelve months have centred round the Faraday Centenary Celebrations and the International Illumination Conference. The great interest of the public in electricity was well shown by the attendances at the Albert Hall Exhibition, also by the vast crowds which flocked to see the unparalleled displays of floodlighting in London and the chief provincial towns. Illumination has thus been the branch of the industry which in 1931 claimed greatest attention, but progress in other branches has not been lacking. It is proposed in this article to show something of the contribution which the General Electric Co., Ltd., has made to the year's electrical progress.

An outstanding achievement has been the equipment of the Furness-Withy liner Q.T.E.V. "Monarch of Bermuda" in which the use of electricity has been extended to the propulsion of the ship, and every other possible service. The magnitude of this undertaking forbids more than passing reference in an article of a general character; a full description is given on a later page.

Another work of great importance, the first results of which are now available, is the experimental investigation of vibrations in turbine wheels and blades, carried out by the Research Laboratories in conjunction with Fraser & Chalmers Engineering Works. The whole subject is fully dealt with in the third article of this issue.

The activities of the Research Laboratories have been devoted to a wide range of problems bearing upon electrical science and manufacture. Brief particulars of some of the results of this work are given in the paragraphs which immediately follow.

ACOUSTICS AND ACOUSTICAL APPARATUS.

The design of loud-speakers and telephone apparatus has now reached the stage at which numerical measurement of performance is taking the place of judgment by ear. It is of course true that the criterion is the effect on a human ear, but till comparatively recently, this has of necessity been applied by obtaining the opinion of a number of individuals. Circumstances inevitably limited the number of opinions available and in any case the interpretation of the results and their translation into design data are extremely difficult.

The procedure nowadays employed in the Research Laboratories consists in measuring the alternating sound-pressure set up in the field of the instrument (*e.g.*, a loud-speaker) under test, while it is supplied with known amounts of energy in the form of pure tones covering the audible frequency range.

In practice the sound is converted by a microphone into an electromotive force, this being the quantity actually measured. A response curve for the loud-speaker is then constructed, which can be interpreted in terms of its effect on the ear. For

this purpose a scale of loudness has been developed which takes into account the sensitivity of an average ear. Fig. 1 gives an example of such characteristics for a loud-speaker for comparison with the characteristics, shown dotted, of a system with true linear response.

In this way it is possible to obtain a numerical measurement of the performance of a loud-speaker as it will affect a hypothetical average listener, the results being in no way dependent on the ear of a particular experimenter. Measurements of the kind just described are carried out in rooms, the walls of which are padded with thick layers of absorbent material to eliminate reflections. It has been necessary to develop special condenser microphones

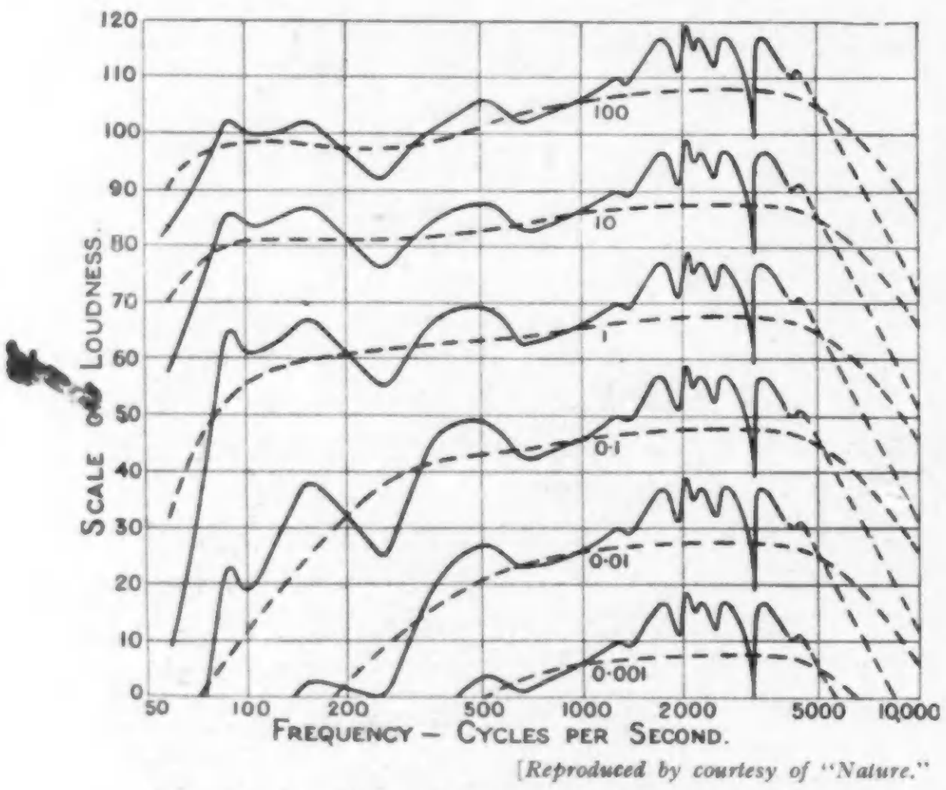

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Fig. 1.—Loudness-frequency characteristics at different sound pressure levels in dyne/cm².

for this work, so as to obtain a more perfect frequency response than has been possible with those hitherto available. Special features are the reduction of the cavity in the face of the instrument and the introduction of quartz insulation for the sake of permanence and quietness in operation. It may be mentioned that although these microphones were intended primarily for use in the Laboratories, they have attracted interest outside, and a number have been supplied to various Government departments and private laboratories. The general appearance of the two types which have been made is indicated in fig. 2.

WIRELESS SETS.

In the case of wireless sets there has been for sometime the same tendency towards appraisal by numerical measurement rather than by ear. Apparatus has been devised for this purpose in which a high frequency oscillator is used, which can be adjusted to any wave-length, the latter being checked by quartz crystal oscillators. The oscillator can be modulated by audio-frequency signals in exactly the same way as is done at broadcasting stations. A very small measured voltage from the oscillator is passed into a circuit representing an average receiving aerial, and this circuit is connected to the aerial and earth terminals of the set under test.

The electrical audio-frequency output from the set is measured for the various adjustments of the set, and by combining these results with the data available for the audible output of the appropriate loud-speaker, the ability of the combination to reproduce music and speech can be accurately determined. The same apparatus is used in studying selectivity, and the results obtained for all these various measurements are used by the Telephone Works in conjunction with the Laboratories in the design of new sets.

In addition to the study of complete sets, the behaviour of the components is also investigated.

Fig. 2.—Condenser microphones.

It has been found that much of the distortion occurring in sets can be traced to the detector valve. The design of detector valves has therefore been reviewed, and for all types of valves which can be used as detectors, graphs have been prepared showing the rectified low-frequency output which can be obtained from any modulated radio-frequency input signal.

DISCHARGE TUBES.

A new so-called "Ripple" effect was described in the *G.E.C. Journal*, Vol. 1, No. 4, "Electrical Progress and Development in 1930." At the time this effect could only be obtained in blue or green colours. It has now been found possible to produce it in neon gas, so as to give the well-known orange hue.

Another interesting line of work is concerned with the "striated" discharge. In all ordinary discharge tubes containing rare gases, the glow in the main portion of the tube is continuous. When, however, common gases such as air or nitrogen

are used, the discharge, under certain conditions, breaks up into a number of separate sections, this effect being known as the "striated" discharge.

In the rare gases, it was only possible to obtain this effect momentarily. As a result of recent work in the Laboratories this type of discharge can now be produced at will in neon, and the effects are very striking and beautiful. The work is, however, still in the experimental stage.

New colours have been developed in cold-cathode tubes, such as are used for advertising purposes.

Hot cathode tubes, the intensity of which is much greater than that of the older cold cathode type, have not yet reached the commercial stage, but their development has been proceeding very rapidly during the past year. Owing to their high efficiency as sources of coloured light, they possess special attractions for use in coloured flood-lighting and for coloured lighting generally. By suitable combinations of colour, however, light for general illumination can be produced and they can also be combined with incandescent lamps to give radiation closely approximating to daylight.

ILLUMINATION.

A considerable amount of work has been carried out in connection with aviation lighting equipment. One outcome of this is a reflector type air beacon, beam candle power tests of which have checked out well with the calculated performance. An aerodrome floodlight has been designed, embodying reflectors, of which there are nine of parabolic trough formation, equipped with 1,000 W. tubular lamps. With the aid of a specially developed focussing device, the unit can be set up in daylight and the results obtained by test at night are very satisfactory.

Work on prismatic refractors for street lighting and for other purposes has been continued and new designs have been evolved. Improvements in prism formation have now raised the efficiency of these refractors to a high level.

The diffusion of light by opal glass has been given further attention and the theoretical work of Ryde and Cooper has been used to develop a practical test schedule for opal glass fittings which enables their efficiency as lighting units to be determined together with the quality of the opal glass as a diffuser.

PHOTOMETRY.

During the past three years, commercial photometry has been passing through the transition stage and visual photometry is steadily being superseded by photoelectric methods of measurement. Three photoelectric photometers are at present in use at the Research Laboratories, and are capable respectively of being used for the following purposes :—

(*a*) Measurement of lumens on a direct reading lumen scale over a range of colour temperatures 2400°K. to 2800°K approximately.

(*b*) Measurement of lumens and colour temperatures, both on direct reading scales.

(*c*) Measurement of lumens and lumens per watt both on direct reading scales.

A photoelectric photometer utilising a cubical photometric integrator of 8ft. side has been installed at the Osram Lamp Works, having a direct reading lumen scale. This photometer has been designed especially for the measurement of very large lamps up to the 10 kW lighthouse size.

Fig. 3.—Hams Hall Power Station, Birmingham. The third turbo-alternator of 37,500 kVA capacity recently installed can be seen in the background.

GLASS AND REFRACTORIES.

The manufacture of special glasses for sodium vapour discharge tubes has involved the provision of suitable pots in which the glasses are melted, and it has been found necessary to produce special refractory porcelains for this purpose. Further new types of coloured tubing have been made for use in neon signs, some of these being already in commercial use. The behaviour of clay mixtures when subjected to the severe conditions of temperature and corrosion which arise in the manufacture of high quality glass has been the subject of investigation and substantial improvements have been effected.

POWER PLANT.

The year has witnessed the placing in commission of further large turbo-alternators in various stations. The new set at Hams Hall (fig. 3) is the third installed with a capacity of 37,500 kVA at a speed of

1,500 r.p.m., while that at Nechells has an output of 30,000 kVA at 3,000 r.p.m. Another large 3,000 r.p.m. turbo-set completed within the last few months is now in service in the Borough of Battersea

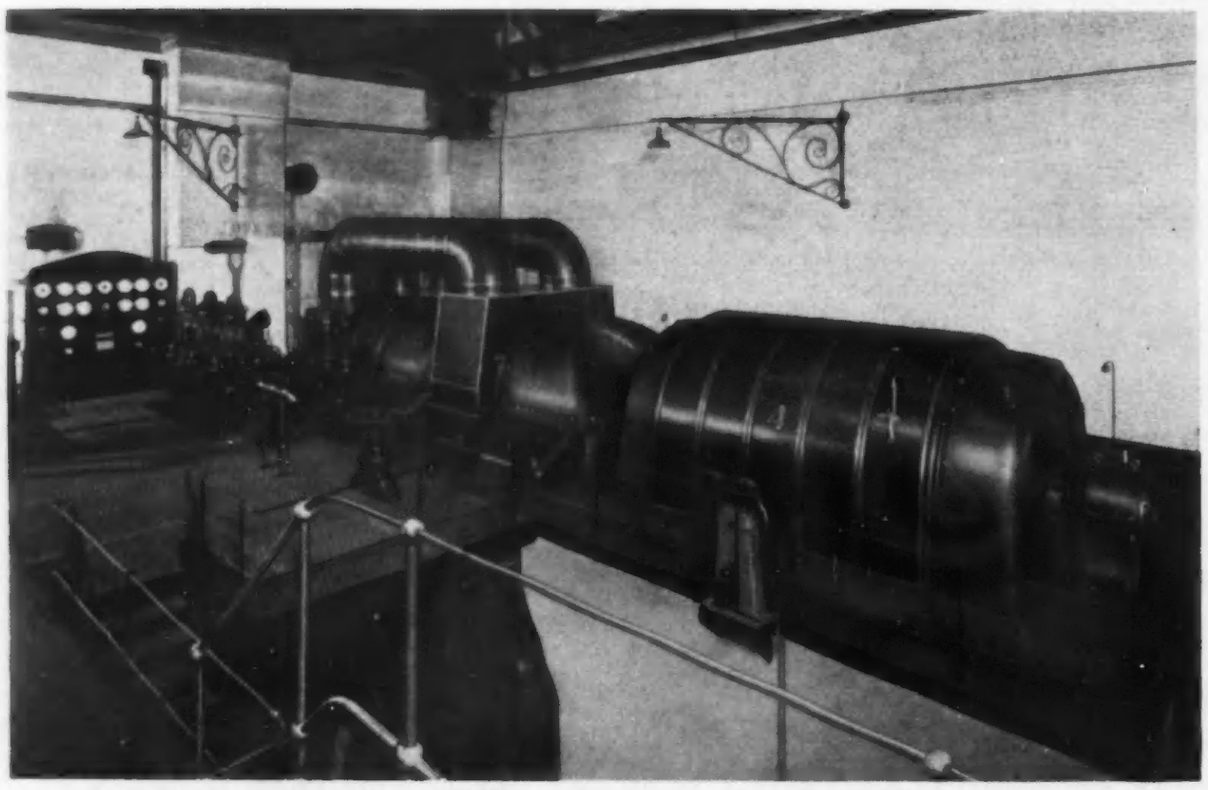

Fig. 4.—37,500 kVA, 3,000 r.p.m. turbo-alternator installed in the power house of the Borough of Battersea.

power house (fig. 4); its output is 37,500 kVA. Of many other generating units built in the period under review one of the most interesting is the 4,000 kVA water wheel alternator, fig. 5, for the hydro electric

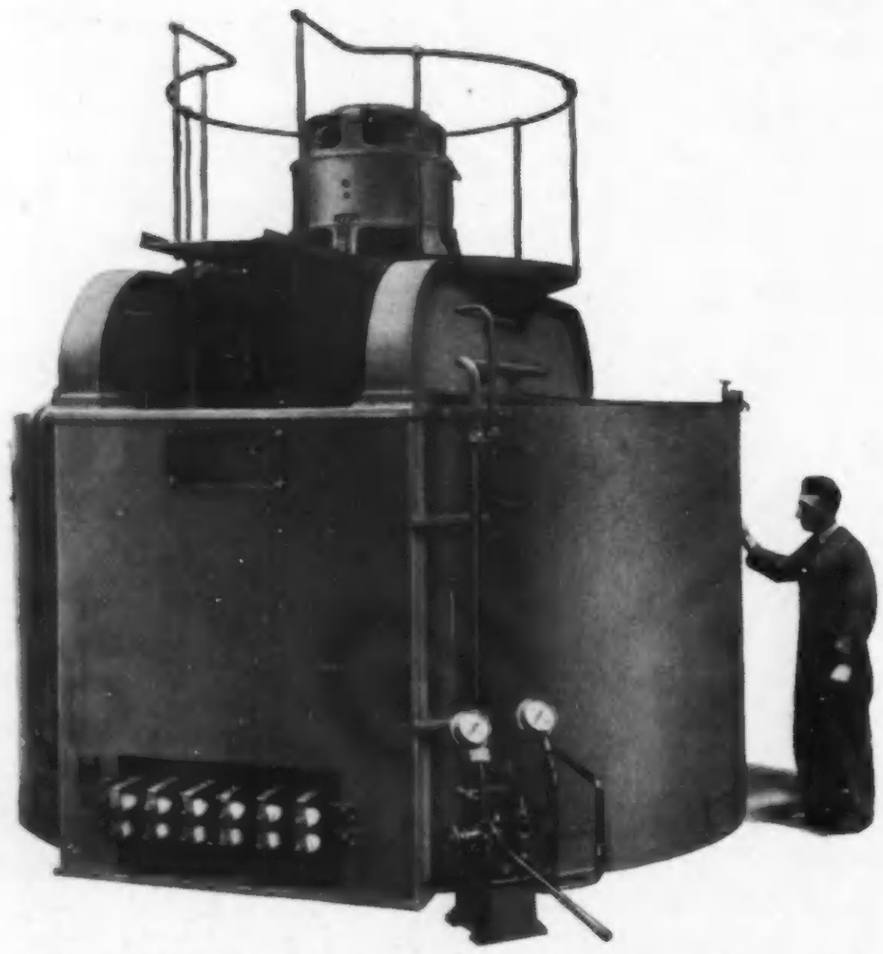

Fig. 5.—4,000 kVA, 514 r.p.m. water-wheel alternator for Pierre's Brook, Newfoundland.

plant at Pierre's Brook, Newfoundland. The machine, which has a speed of 514 r.p.m., had to be designed and constructed so as to ensure a very high degree of reliability, in view of the fact that it has to run in a station where there is usually no attendant. The method of fixing the poles embodies a newly patented principle supplanting the method of dovetailing previously employed. By reference to fig. 6, it will be seen that an extension at the lower end of the pole is fitted into a rectangular groove in the magnet wheel and secured by means of pins. One point of superiority of this construction over the dovetail lies in the fact that all bending stresses are avoided, and there is only a shearing stress on the pins. Further advantages are that the cost of machining is reduced and the poles are more easily assembled. Each pole, with its field coil, can be dropped into position from outside, whereas with dovetailing it has to be forced along the length of the magnet wheel.

In view of the depressed state of the colliery and mining industry, it is gratifying to be in a position to record some activity in winding equipments.

Five electric winders, together with a considerable amount of colliery equipment are in course of manufacture for the Usworth and Ryhope collieries on the N.E. coast. For Usworth Colliery, Durham, two A.C. winders of 1,000 and 200 h.p. are being supplied. The former is of particular interest as it is the largest yet constructed for this district. Both winding motors are of the slipring induction type, working off a 2,750-volt 3 phase 40/50 cycle supply.

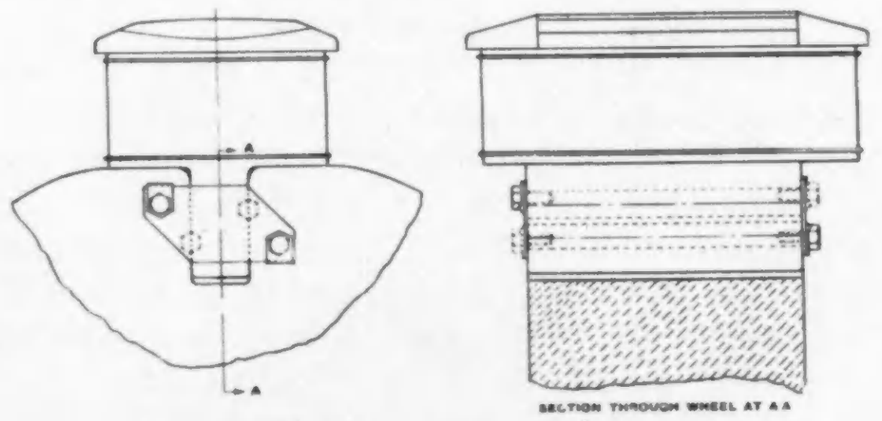

Fig. 6.—Method of fixing poles used for the 4,000 kVA alternator shown in fig. 5.

Two 550 h.p. air compressor slipring induction compressor motors are also included in this contract.

At Ryhope Colliery a conversion scheme for steam to electric drive is in progress. Three winders, previously driven by beam engines, are to be driven by slipring induction motors, one being designed for 900 h.p. normal capacity and the other two for 500 h.p. It is planned that the work involved in the conversion shall be carried through without interruption to the running

of the plant. Two 600 h.p. air compressors units will also be converted from steam to electric drive at this colliery, while the motors to be installed for various purposes have an aggregate capacity of 3,000 h.p.

Six of the motors, each of 100 h.p., are employed for underground haulages and are of a special drip-proof construction with explosion-proof slipring covers, fig. 8.

Two induction motors with control gear for driving winding gears have been shipped for the South African Gold Mines. The larger of these was rated at 2,200 h.p. normal load, and the smaller at 1,550 h.p.

The principal rolling mill motors built have been for driving Fraser & Chalmers Bliss type rolling mills, which are described at a later stage of this article. In general Bliss type mills are driven by D.C. motors controlled on the Ward-Leonard principle.

MERCURY ARC RECTIFIERS.

As a result of development work over a period of years, mercury arc rectifiers have been constructed for loading capacities up to 3,600 amps. at 800 volts D.C. continuous loading. In particular, attention has been given to rectifiers for traction work, and there are now in hand thirteen rectifiers of 1,500 kW output and two of 1,200 kW output with automatic control equipment, for two prominent railway companies.

In traction service, rectifiers are called upon to operate under very rapidly changing loads, and to deal with peak currents far in excess of their normal rating, which they must be capable of bearing immediately after being switched on to the line when cold. Tests upon rectifiers with varying loads, including short circuits, have been made without failure under far more severe conditions than are likely to occur in actual service.

One of the main features of construction is the introduction of a vitreous insulating anode seal which renders the use of perishable rubber or auxiliary mercury seals unnecessary, and reduces the number of vacuum-tight joints required. Rectifiers constructed with these anode seals have shown remarkable vacuum-tight properties. The use of rubber or mercury seals limits the working temperatures of certain parts of a rectifier, and this is detrimental to its most satisfactory operation. With this new construction, it is as easy to remove a complete anode assembly as it is to remove an ordinary cylinder cover.

Another improvement is the elimination of porcelain or similar materials as a support for internal components.

Fig. 7.—Power station of Messrs. Boots, Ltd., Nottingham, showing three 1,250 kVA geared turbo-alternators, 400 volts, 3 phase, 50 cycles.

FRAME COOLED MOTORS.

The introduction of a range of frame-cooled motors, fig. 10, for use in gas works, chemical works, collieries, quarries, etc., has overcome the difficulties hitherto associated with totally enclosed motors, which had to be of excessive dimensions for comparatively small outputs. The method of ventilating frame cooled motors involves the use of a shell with a double wall casing, the annular space between the walls being divided into sections by longitudinal ribs to form ventilating ducts, which are arranged to give two separate circuits for internal and external air flow, adjacent ducts being in different circuits. Air is blown round the internal circuit by a fan at

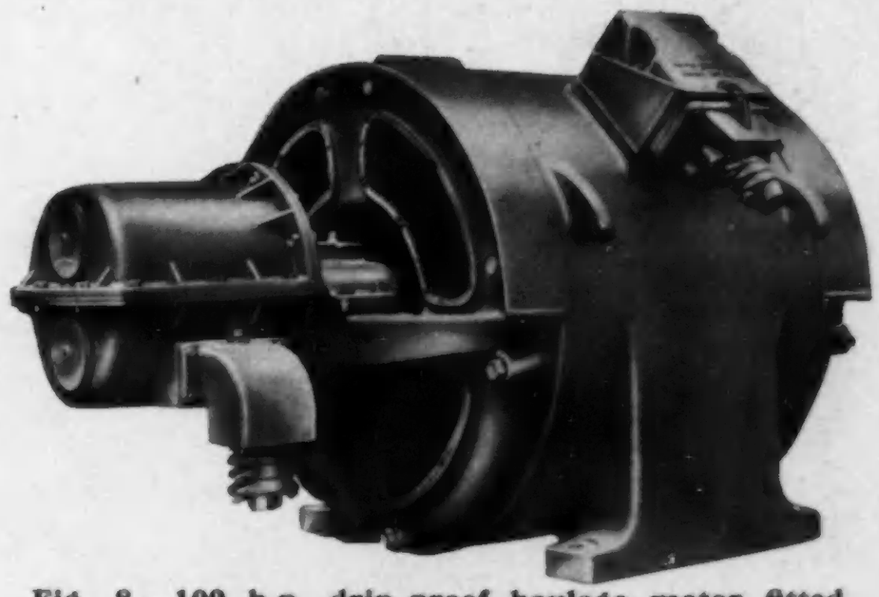

Fig. 8.—100 h.p. drip-proof haulage motor fitted with explosion-proof slipring covers.

the driving end whilst a second fan forces a continual flow of cool air through the adjacent external ducts. In this way the heat is transferred from the totally-enclosed part of the motor to the external ducts

and carried away. By the use of this double circuit ventilation, all parts of the motor are adequately cooled and there is no possibility of air remaining stationary in any part of the machine forming hot pockets.

It is of interest to record that a large Canadian

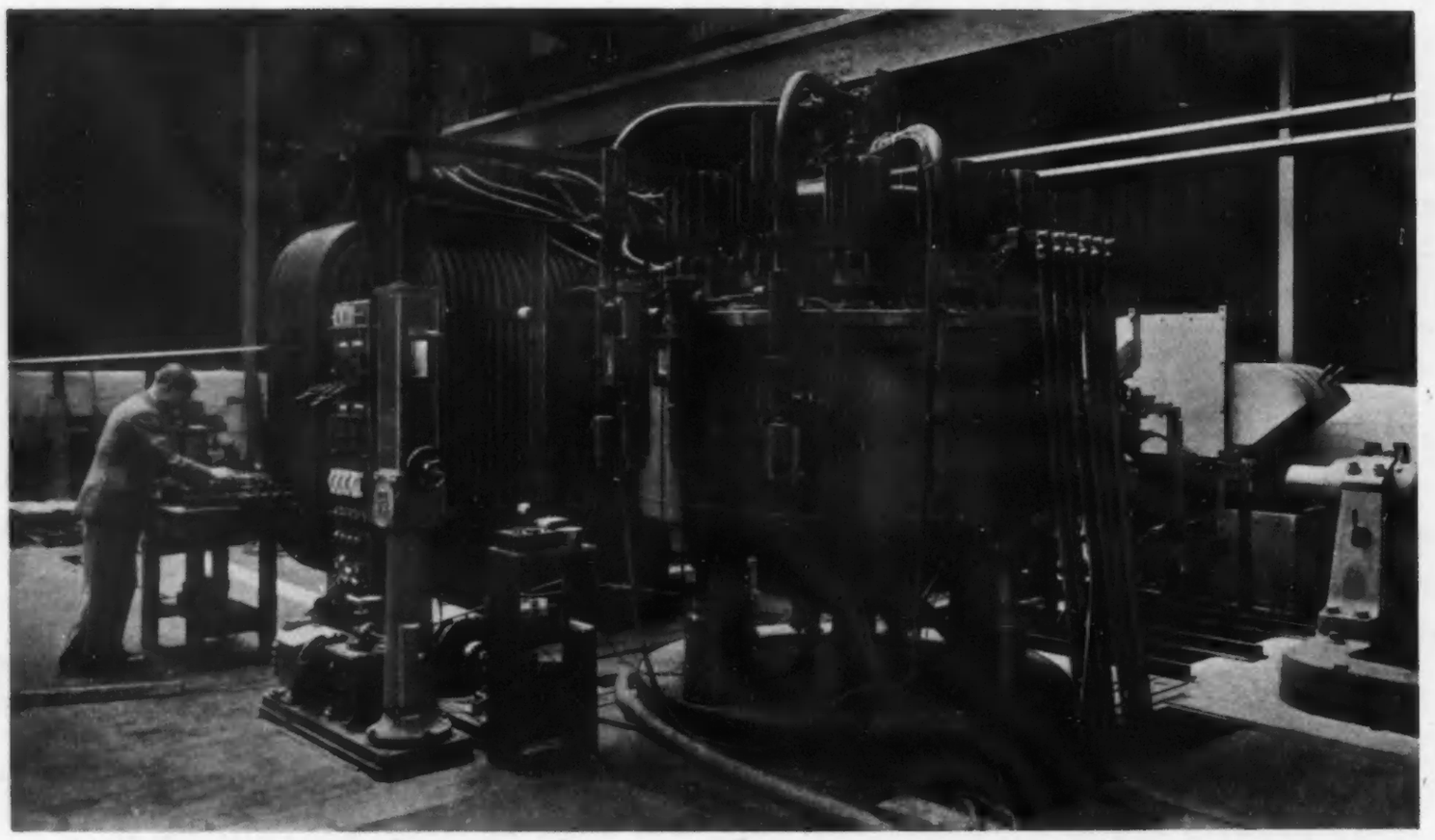

Fig. 9.—2,000 kW, 650 volt mercury arc rectifier on test in Witton Engineering Works.

Gas Works is being completely equipped with these motors.

SMALL MOTOR DEVELOPMENTS.

A range of small single phase motors has been

Fig. 10.—Frame cooled squirrel cage motor showing the extended duct outlets of the bearing bracket.

developed for purposes where high starting torque is required. Starting is effected on the A.C. repulsion principle, with the characteristic of high torque and low starting current. At a speed approaching synchronism, the machine automatically reverts to the pure induction type with the characteristic of nearly constant speed.

The rotor is of the wound type, and carries a commutator of radial construction. A governor arranged at the opposite end of the rotor, operates to remove the brushes from the commutator and short circuits the winding at a pre-determined speed. The design is arranged so that the overall dimensions are the minimum possible. The motor is silent in action.

A new gramophone motor for A.C. circuits, fig. 11, is being produced in large quantities. It is a self-starting induction type of slow speed machine, arranged for direct drive. The speed of the turntable is maintained constant by means of a governor assisting the flywheel effect of the rotor, even over

Fig. 11.—A.C. gramophone motor.

difficult track portions of the record. An automatic switch of novel construction is incorporated to cope with the variation in size and finish of the records at different diameters. This has previously involved a switch which needed setting to suit each fresh record. The new switch will work on any record which has a finishing run-in groove, regardless of the diameter of the finishing groove, and hence does not need any setting to suit the record. The functioning of the switch is brought about by the difference

in the rate of radial motion imparted to the needle by the finishing groove. The whole of the switch mechanism is contained under the turn-table.

Certain processes involved in the manufacture of artificial silk have necessitated the production of a large number of small motors having extremely high speeds, of the order of 10,000 r.p.m. One of the chief difficulties met with in their design was to provide a suitable form of lubrication which could be applied continuously and in very small quantities. The problem was satisfactorily solved in the following manner. A current of air is driven through the bearings in a closed circuit. The air stream is arranged to pass through an oil spray caused by a projection on the vertical shaft dipping into an oil well at the bottom of the motor. The air stream becomes loaded with particles of finely atomised oil, which is deposited on the bearings in a perfectly even and regulated manner. This new method, which has been protected by patents, promises to solve the lubrication difficulties of ultra-high-speed motors.

METALCLAD SWITCHGEAR.

For large power station work, and indeed for many smaller power stations and substations, metalclad switchgear was adopted in 1931 to a greatly increased extent. Many boards for installation both at home and abroad have been constructed, and development in design has been continuous. It is not possible in the space available in this article to refer to detailed improvements in construction, but certain general tendencies in design should be mentioned.

Considerable advance has been made towards higher efficiency in the operating mechanism of the larger metalclad circuit breakers, by the introduction of compressed air as the motive power. This means of operation has considerably simplified the link work in the mechanism, thereby reducing the weight of the moving mass which has to be accelerated and retarded during the opening and closing of a breaker.

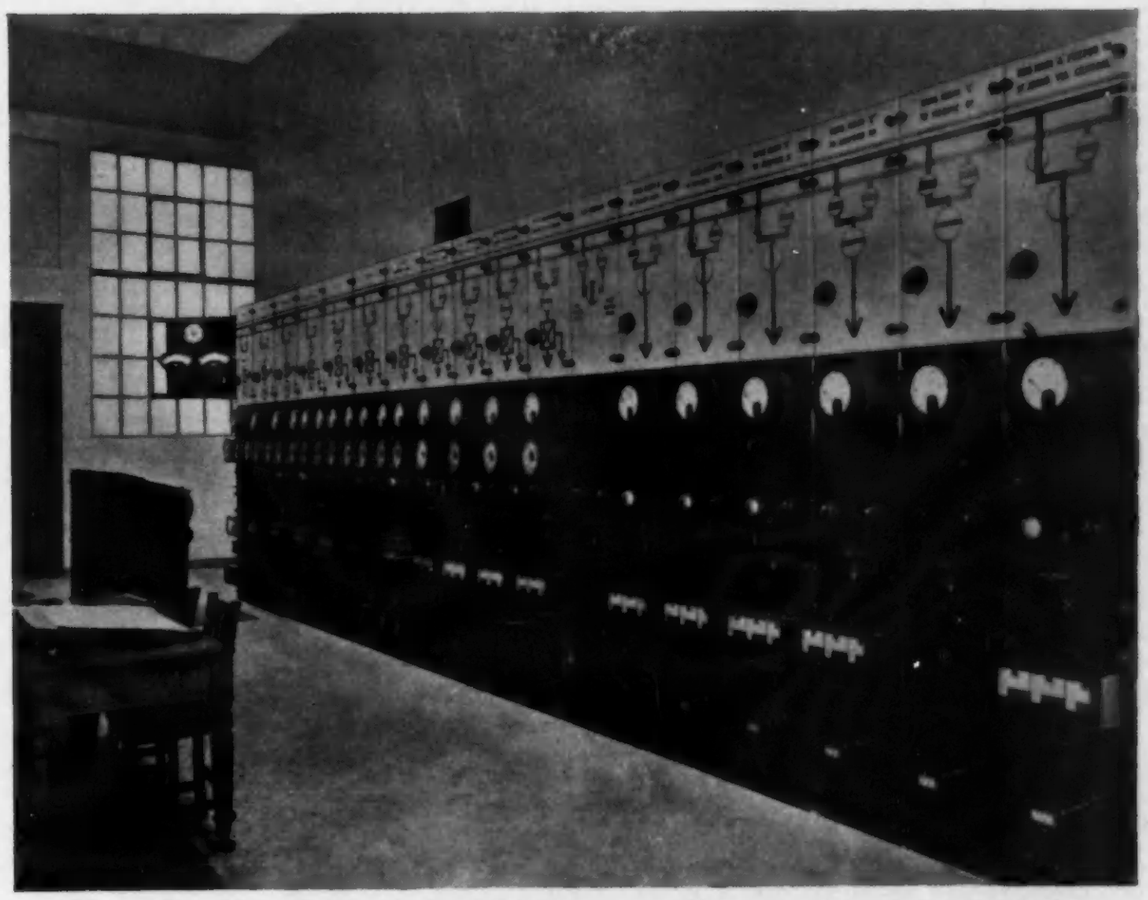

Fig. 12.—Control board at Eastbourne Corporation power station, operating metal-clad switchgear shown in fig. 13.

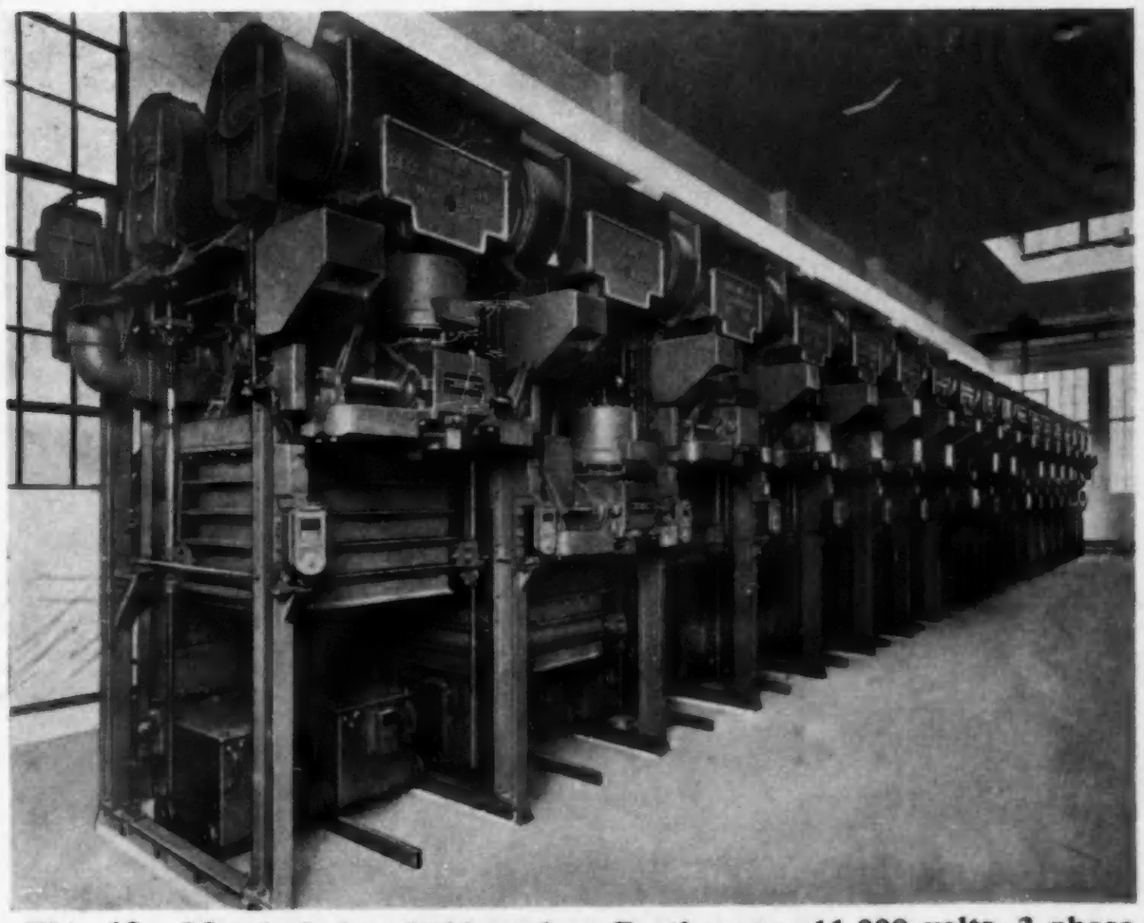

Fig. 13.—Metal-clad switchboard at Eastbourne, 11,000 volts, 3 phase, 50 cycles, 350,000 kVA breaking capacity.

From the point of view of manufacture, largely increased use has been made of aluminium alloys, which are employed not only for compound filled chambers, but for detail parts such as bearing housings, clamps, brackets, cables, small operating levers, etc.

In the form of castings, aluminium is probably the ideal metal for chambers which have to be filled with oil or compound, providing as it does a ductile non-magnetic casing having a high thermal conductivity. The use of this metal can reduce the weight of a metal clad unit by approximately 10 per cent over a similar unit using cast iron or similar metals for castings.

The use of drawn and extruded aluminium alloy in the moving contact system effects a considerable reduction in the weight of the moving mass with a

corresponding reduction in the energy required to close or open a breaker.

The design of busbars has been a matter of investigation especially in those cases where the proximity effect is increased by the restricted spacing necessary for compound filled designs. With the usual laminated type of bar, the combined skin and proximity effect interfere to such an extent with the current distribution in the cross-section of the bars—thus increasing the apparent resistance and the heating—that when a current of about 3,000 amps. is exceeded, the temperature cannot be reduced to any serviceable extent by adding to the number of

Fig. 14.—Outdoor switching station at Hams Hall, Birmingham, showing 132,000 volt, 300 amp. oil circuit breakers, isolating links, etc.

laminations or to the cross section of the copper. One reason for this is that the various laminations are not in contact, and therefore the conductors which are carrying much less than their proper share of current remain at a much lower temperature than the others. Since there is no direct metallic connection between them and those laminations which are more heavily loaded, there is no transference of heat between them, and they do not therefore serve to conduct the heat away from adjacent bars and assist in dispersing it.

These difficulties have been overcome by the introduction of the tubular type of bar. Not only are skin and proximity effects much reduced on account of the symmetry of the section, but as the bar consists of one piece of metal, heat is readily dissipated round the whole circumference. With the larger sizes, each separate bar is contained in its own tubular casing, with the annular space, which is of course filled with compound, made of thickness suitable for the voltage of the gear. There is thus a most efficient path provided for the passage of the heat through the bars to the surrounding atmosphere.

AUTOMATIC OPERATION AND REMOTE CONTROL.

The development of automatic equipment for large mercury arc rectifiers has led to a great simplification of control gear.

The mercury arc rectifier has created a demand for a reverse current high speed circuit breaker to minimise the effects of back fires. For this service a low setting in the reverse current direction is required. Such a setting would normally cause instability upon fluctuating loads in the forward direction. This difficulty, however, has been completely overcome and a design of breaker is available which will trip with a reverse current of 50 per cent full load, and at the same time possesses characteristics rendering it perfectly stable if 200 per cent full load in the forward direction is suddenly thrown off.

It is convenient to mention here that high speed circuit breakers for general purposes are designed for 5,000 amps. at 1,500 volts.

Progress in automatic working relates also to the synchronising of generating units including the automatic sharing of loads, the automatic control of power factor, and the automatic regulation of frequency.

Remote control and supervisory methods are being much extended in use. Specific instances are the supervision of the working of the various areas of the "Grid" from one central point in each area, also the control from one point of a series of converting substations located along electrified railway lines. A great number of other cases could be mentioned, of which an interesting example is afforded by a simplified supervisory equipment primarily for use on rural distribution systems at 11 kV or 33 kV. The equipment works over 4 pilot wires which loop into any number of substations up to a maximum of 30. At each substation ten separate operations can be performed which may include :

(*a*) Opening or closing oil circuit breakers.
(*b*) Control of on-load tap changing switches on transformers.
(*c*) Control of induction regulators.
(*d*) Meter readings.
(*e*) Telephone, etc.

As ten separate operations are available the scheme can be used for many other purposes in addition to that for which it was originally designed. The new equipment is very much less costly than the standard supervisory equipment capable of carrying out a much greater number of independent operations. Provided, however, that the total

number of operations does not exceed ten, it is in every way reliable and efficient. Moreover, it can be adapted for application to kiosks or pole mounted transformers.

PROTECTIVE GEAR.

With the increase in the size of alternators in power stations, danger from internal faults is also increased, and in particular the time required to burn out the insulation is greatly reduced. The amount of power available in a fault of even a small percentage of full load reaches a high value when the normal rating is 40,000 or 50,000 kW; and since the relay must trip before any protective action is initiated, sensitivity is of first importance.

A decided advance in this respect was achieved by the relays installed in certain super-stations where a sensitivity as low as 4 per cent at normal full load has successfully been employed. The problem of securing stability at this low setting was overcome by the bias characteristic of this form of protection, the relays actually operating when faults occur in the vicinity of 4 per cent of the load that is passing at any particular instant, whether this is a

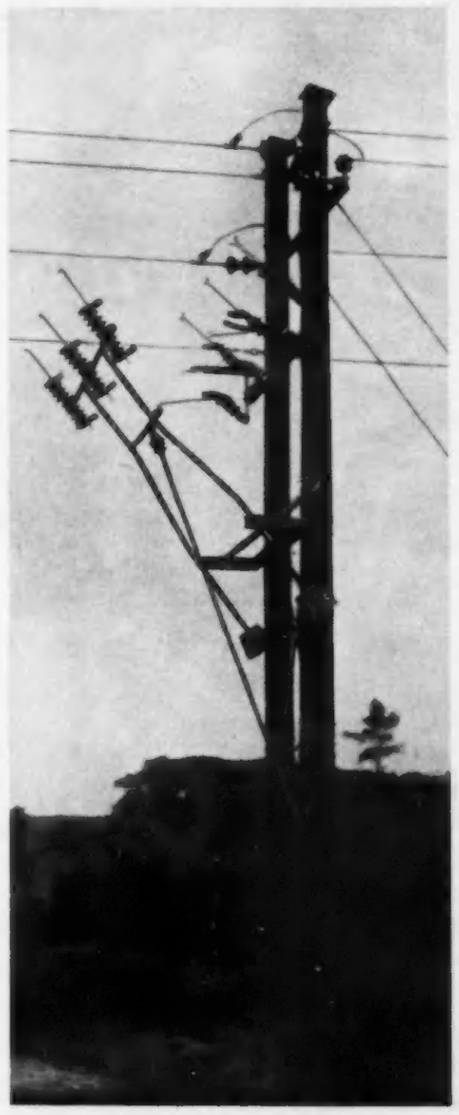

Fig. 15.—Drop down switch fuse installed on rural line in Cornwall.

fraction of the rated value or a current of many times normal.

A peculiarity of generators as regards isolation of a faulty winding is that the tripping of the circuit breaker only opens the outgoing terminals, leaving the internal short circuit still untouched. Consequently if no other measures are taken, the machine will still continue pumping energy into the fault. The fault current can only be brought to zero by suppressing the excitation of the generator com-

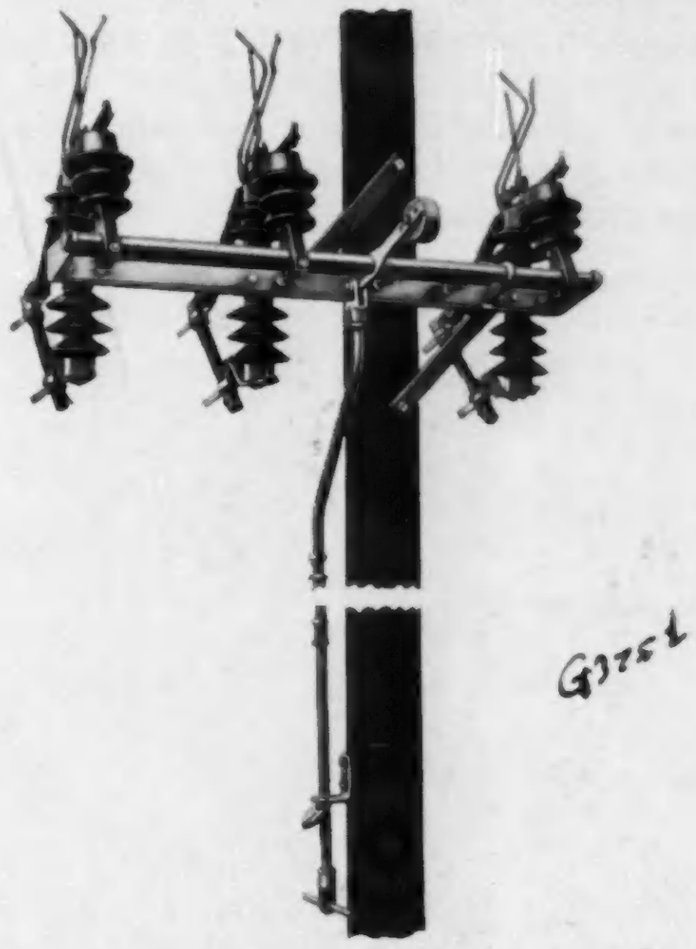

Fig. 16.—Gang-operated air break switch for mounting on single wood pole.

pletely, and this should naturally be done as rapidly as possible. In the relays installed in the super-stations referred to, the initial out-of-balance due to the fault releases a multi-contact drum, which not only trips the circuit breaker but brings about the instant open circuiting of the field, closes the ventilating doors, and if necessary also trips the emergency stop valve of the turbine. The open circuiting method is the most effective way of bringing about the disappearance of the flux, as it is well known that other methods, such as short circuiting the field winding, may delay the reduction of the flux to approximately zero by as much as half a minute.

In a number of situations it is an advantage to give protection against negative phase sequence currents, and a type of protective scheme has been devised which is not only stable and sensitive, but is unique in that for the first time it confers all the advantages of a bias with negative phase sequence currents. This scheme is being applied to the protection of 132 kV feeders, and is of special value for feeder sections terminating at unattended sub-stations which do not possess a circuit breaker. This type of protection is also valuable with large generators since the negative phase sequence current can cause serious heating of the end shields and other parts of the rotors, and the scheme is also being applied to this purpose.

A form of protection based upon Kapp-Carrothers patents has been applied during the year to e.h.t. feeders. The system requires only a single pilot conductor, and it has proved particularly suitable for long feeders where expense would not warrant the installation of a multi-pilot wire system. It possesses an important advantage over an impedance scheme in that a time lag is not a necessary feature. Complete stability is assured as isolation of a section cannot take place due to a fault current passing out of the section protected.

involves the manufacture and erection of eleven 132 kV outdoor substations at Oxford, Portsmouth, Southampton, Bourne Valley, Dorchester, Exeter, Bridgewater, Newton Abbott, Plymouth, Fradden and Hayle. A total of thirty 3-phase 132 kV outdoor oil circuit breakers will be employed, each having a breaking capacity of 1,500,000 kVA. The contract includes provision of all isolating links, post and suspension insulators, structural steelwork, etc.

Advances have been made in the design of outdoor air-break switchgear, and the range of

Fig. 17.—View in Witton Transformer Works, main assembly bay with test pit in the foreground.

CONTACTOR APPARATUS.

The range of contactors is being continually extended. A recent air break model, designed for use with a large mining hoist for South Africa, is rated at 6,600 volts, 400 amps. A variant of this model has been applied to marine work. Attention has also been directed to small contactors of the order of 5 to 25 amperes. The breaking capacities of all have been improved and a new type of moulded blow-out has been produced for the A.C. models which dispenses with the blow-out coil, but nevertheless gives increased breaking capacity. The 5 ampere model has been designed with a latch and enclosed in a cast iron case for switchboard mounting in order to indicate when switches are open or closed.

OUTDOOR SWITCHGEAR.

A further contract has been obtained for the Central Electricity Board in connection with the South West section of the "Grid." The work

equipment in this class has been extended to include new types of inexpensive air-break switches and fuses designed for use on rural electrification schemes. The gang-operated three pole air-break switch and fuse illustrated in fig. 15 is particularly suitable for the protection of transformers up to 200 kVA on rural or suburban lines. The fuses are of the expulsion type, each consisting of a porcelain barrel enclosing the fuse wire which is mounted between contacts at the ends of the barrel. The lower end of the latter is left open, but the upper end is sealed so that the products of combustion caused by the blowing of the fuse are quickly expelled from the lower end of the barrel after the fashion of a rifle discharge. Small arcing horns are fitted to permit of small currents up to 8 amps. at 11 kV being ruptured. By means of a system of levers and counterweights the three fuses can be lowered quickly and easily for inspection or renewal.

A small combined 3-phase air-break switch and

fuse has also been produced for single pole mounting fig, 16, and provides a very inexpensive but efficient method of controlling and protecting transformers up to 100 kVA. The complete unit is extremely compact, the three phases being gang operated from ground level by a simple lever. The fuses are of the same type as those just described.

TRANSFORMERS.

Apart from work in connection with 30,000 kVA, 132,000-volt transformers for the Grid, a large number of extra high tension transformers have been manufactured and installed for overseas service. A view of a typical sub-station in which three such units are installed is given at fig. 18.

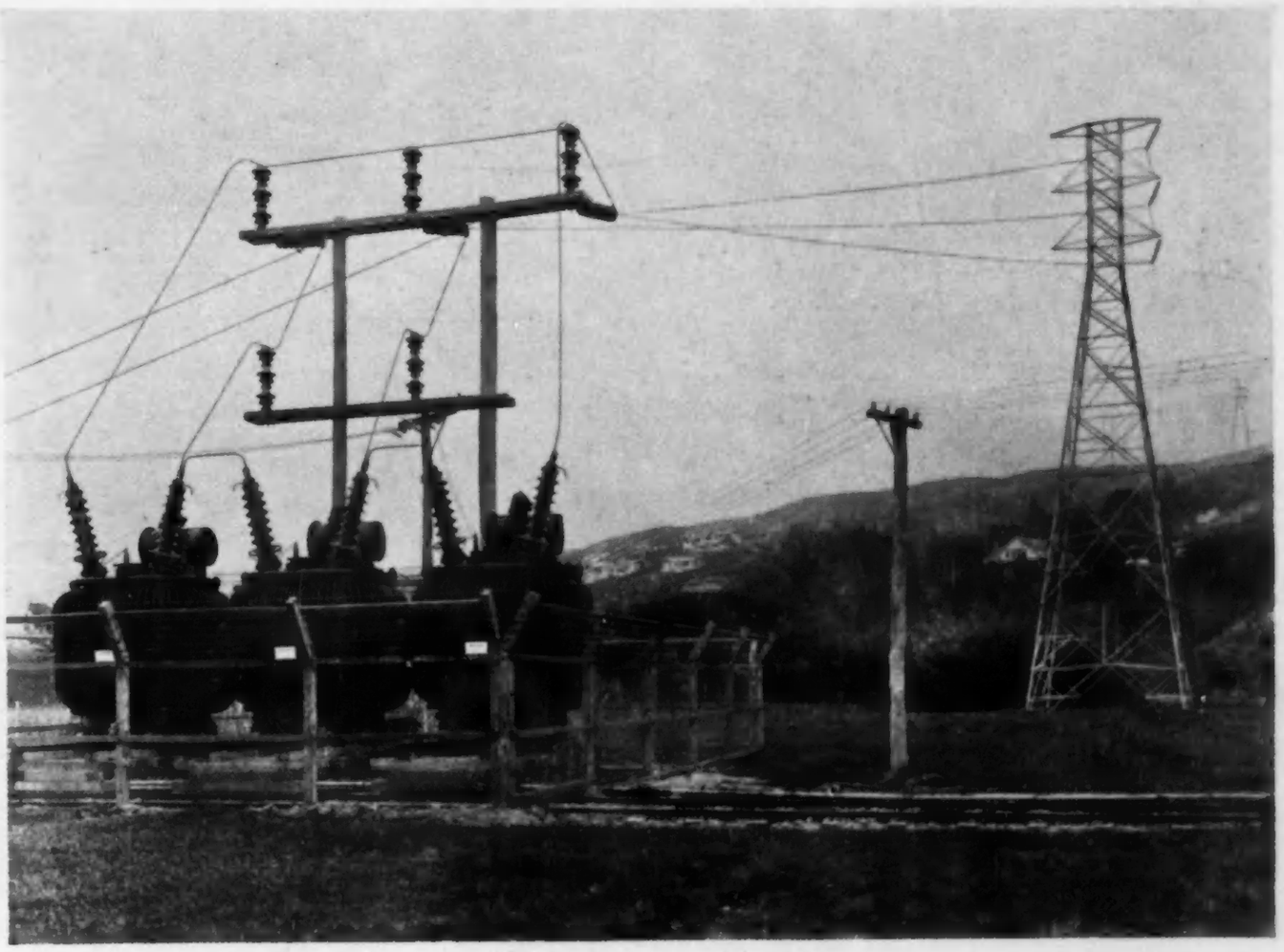

Fig. 18.—Three 1,500 kVA single phase transformers forming a 4,500 kVA, 3 phase transformer bank, 110,000/6,350 volts, 50 cycles, at Mangahao, N.Z. Altogether, nine of these units have been supplied.

Two 1,650 kVA 3-phase transformers and thirteen 675 kVA single phase transformers are in course of manufacture for the supply of traction mercury arc rectifiers referred to previously in this article. The former are of standard design; the latter of the air blast type. The three-phase units are star connected on the primary side, and double six-phase on the secondary side; interphase reactors of special design are used between the neutrals. The air blast transformers are connected in sets of three, being star connected on the primary and double diametric on the secondary. The usual D.C. smoothing chokes are incorporated in each case.

Interest attaches to seven 10,000 kVA, 120,000 volt transformers in hand for export, which are to be supplied with off load tap changing switches. The system on which they will operate is isolated from earth so that the tap changing switches have to be insulated for the full pressure test of 243 kV to earth.

Several detail improvements have been incorporated in the ranges of on load tap changing gear. As this whole subject was dealt with in the *G.E.C. Journal*, Vol. 11, No. 3 ("Load Ratio Control for Transformers,") further reference is unnecessary.

ELECTRIC TRACTION.

Two outstanding railway electrification schemes have been successfully completed in the last twelve months. One comprised the equipment for the new subway line of the Buenos Aires Terminal Central Railway while the other was for the L.M.S. & L.N.E. Joint Manchester-Altrincham line, fig. 19, and comprised the first 1,500 volt equipment constructed since the Ministry of Transport adopted this voltage as a standard. Both schemes have been fully described in the *G.E.C. Journal*, Vol. 2, respectively in issues Nos. 1 and 2. Apart from these two electrification schemes reference should be made to two 550 h.p. shunting electric locomotives for the Chinese Engineering and Mining Co., in connection with the electrification of their Chingwangtao lines. Apart from these specific achievements, a large number of railway and tramway type motors with control equipments have been manufactured. Of interest in the design of railway type motors is the decided tendency to adopt roller bearings. These

are being incorporated in new motors and, in addition, a large number of motors are continually being converted from plain to "roller" bearings. This

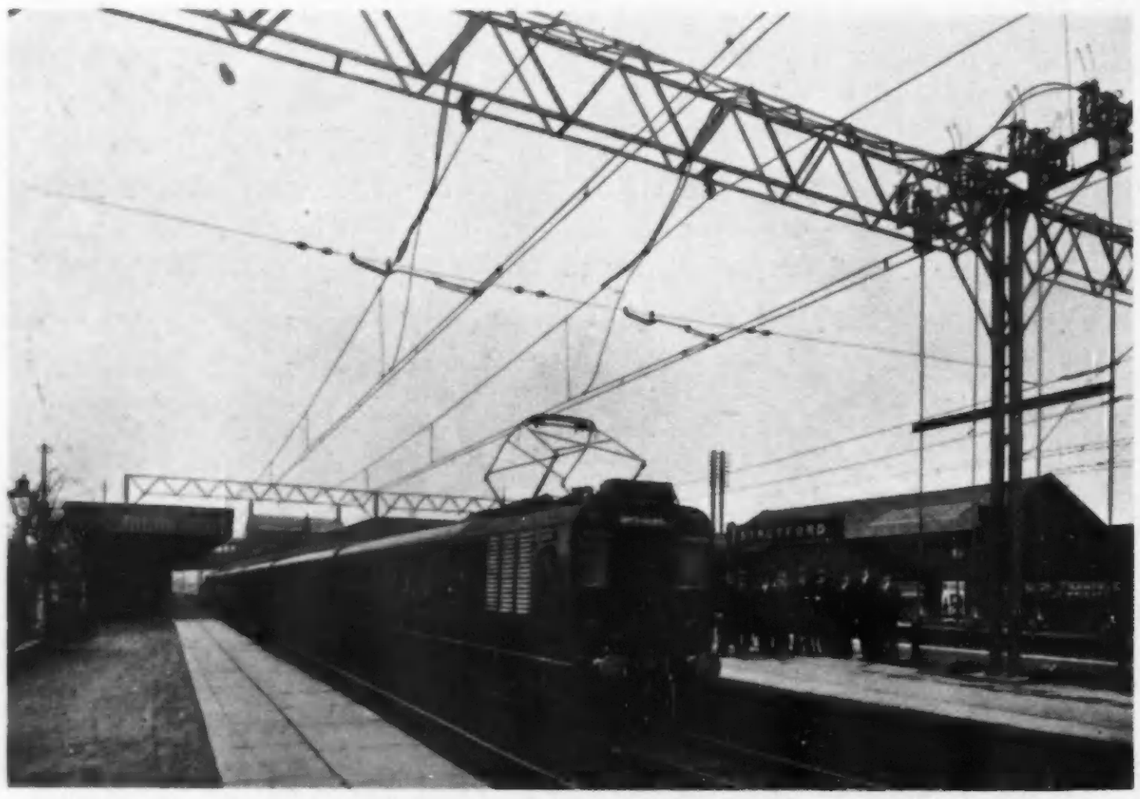

Fig. 19.—A six-coach train unit on the Manchester, Altrincham and South Junction Railway.

statement applies in the case of some of the largest traction motors yet built in this country. The use of roller bearings for these motors has involved considerable investigation into problems of lubrication, and successful methods of lubrication have been evolved.

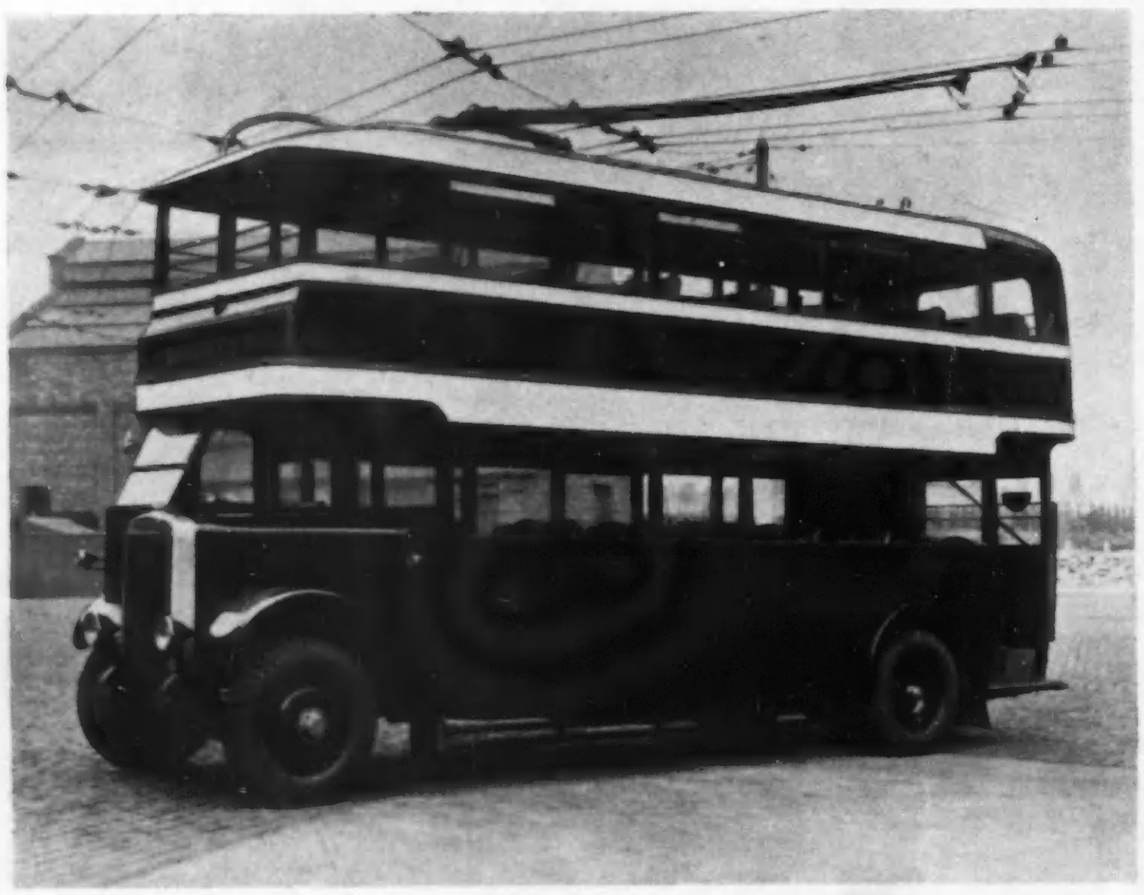

Fig. 20.—One of the new Leyland-General Electric trolley 'buses.

Certain features of motor coach equipment manufactured for the Metropolitan Railway should be mentioned. Each coach is provided with four 210 h.p. 535 volt motors, each pair of which has its own control equipment. There are thus two complete groups of control equipment, and each is so mounted on a frame as to afford a maximum of accessibility. Either group can be cut out in case of fault, leaving the other group operative.

The electric-pneumatic type of contactor has been adopted, and is designed to be capable of service on a 1,500 volt circuit, if necessary at a later date. The control gives automatic acceleration and is worked on the potentiometer system. In order to avoid wastage of current in the potentiometer, the master controller switches off the supply to the potentiometers throughout the train whenever it is moved to the "off" position. Remote control of lighting is provided, operation being possible from several points in the train.

A new departure has been the electrical equipment of trolley buses (fig. 20). The motor for a trolley bus is a high speed machine with normal one hour speed of 1,200 r.p.m., but capable of running up to 3,500 r.p.m. Its normal load rating is 65 h.p., but tests made have shown that sparkless commutation is obtained with 100 per cent overload.

An interesting feature of the G.E.C. trolley bus motor is its three point suspension in the chassis, similar to that of a petrol engine. The necessary flexibility which acts as a preventive of frame cracks is thus afforded. The control equipment for these motors is foot operated, and consists of a master controller actuating a bank of contactors under the bonnet.

STEAM TURBINES.

Reference was made in an earlier section of this article to a 37,500 kVA, 3,000 r.p.m. turbo-alternator for the Borough of Battersea. The turbine of this set offers an example of a modern large capacity high speed machine. The turbine has been made in two casings on account of the increased length necessitated by the double flow exhaust arrangement.

A unique type of power station equipment is that shown in fig. 21. The turbine on the right is the largest pass-out turbine driven d.c. generator set installed this year in an industrial undertaking in Great Britain. The capacity of the generator is 5,000 kW, and the turbine passes from 20,000 to 60,000 lbs. of steam per hour as desired at a constant pressure of 15 lbs. per sq. inch.

A turbine of the combined type (fig. 22) has been developed for small and medium capacities, which requires the minimum of space and foundation. The condenser is arranged beneath the turbine with its axis at right angles to that of the turbine. The centre portion of the condenser shell is cast in one piece with the bottom half of the turbine exhaust casing, thereby eliminating a joint between turbine and condenser.

The arrangement of this turbine further ensures that although compact in design, the various items of equipment are very readily accessible. Several of the machines have been installed both at home and abroad for purposes of public electricity supply, also in railways, colliery and other industrial undertakings.

In addition to progress in electrical plant there are certain developments in mechanical equipment made by Fraser & Chalmers Engineering Works to which reference should be made.

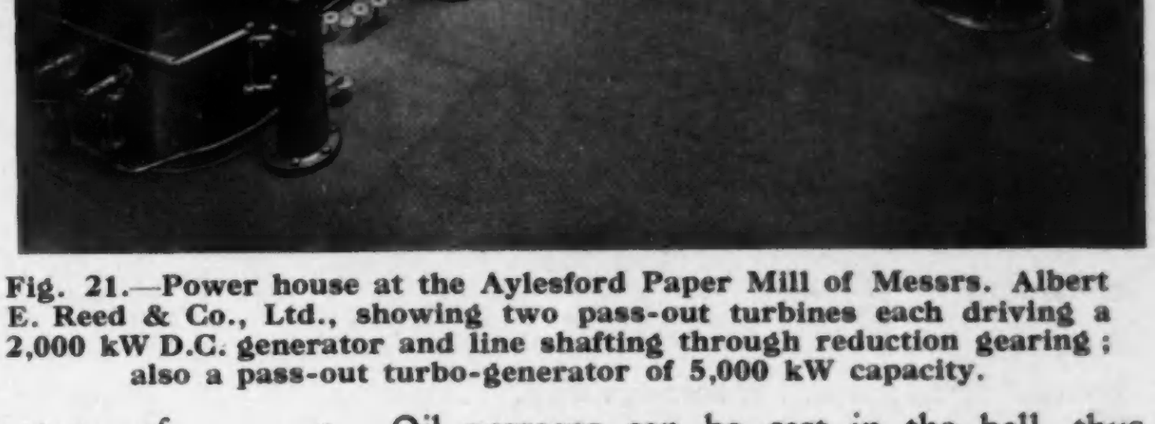

Fig. 21.—Power house at the Aylesford Paper Mill of Messrs. Albert E. Reed & Co., Ltd., showing two pass-out turbines each driving a 2,000 kW D.C. generator and line shafting through reduction gearing; also a pass-out turbo-generator of 5,000 kW capacity.

OIL ENGINES.

The principal feature of progress in the design of Fraser & Chalmers oil engines has been the adoption of a spherical ended gudgeon connecting rod. The decision to standardise this type of connecting rod was arrived at from results obtained from two engines which had run approximately 5,000 hours. The wear on the spherical aluminium bearing and hardened steel spherical top end was found to be immeasurable. The fact that the piston rotates during working adds considerably to this freedom from wear. Prior to the adoption of aluminium as a metal for heavily loaded bearings for piston crosshead duty, doubts had been felt as to its suitability for withstanding pressures of 1,200 to 1,500 lbs. per sq. inch, even when working in combination with case hardened steel. The evidence of the test entirely removes these doubts.

Since the spherical gudgeons were made, important developments have taken place in regard to steel. Two new engines now being manufactured are to be fitted with spherical gudgeon pin bearings, and in the light of past experience it has been decided to adopt special steel castings for the ball instead of forged steel which was previously used. The steel is an electric alloy with a small percentage of chrome molybdenum. When heat treated and air hardened the Brinnel hardness is 350, little below that of case hardened carbon steels. The special cast ball has several advantages:

1. The reciprocating weight of the spherical end is lighter than if made of forged steel.
2. Oil passages can be cast in the ball, thus improving to a large extent the inlet and outlet circuits for the cooling oil.
3. The sphere is much cheaper to manufacture.
4. The connecting rod end securing the sphere is also a much cheaper construction.

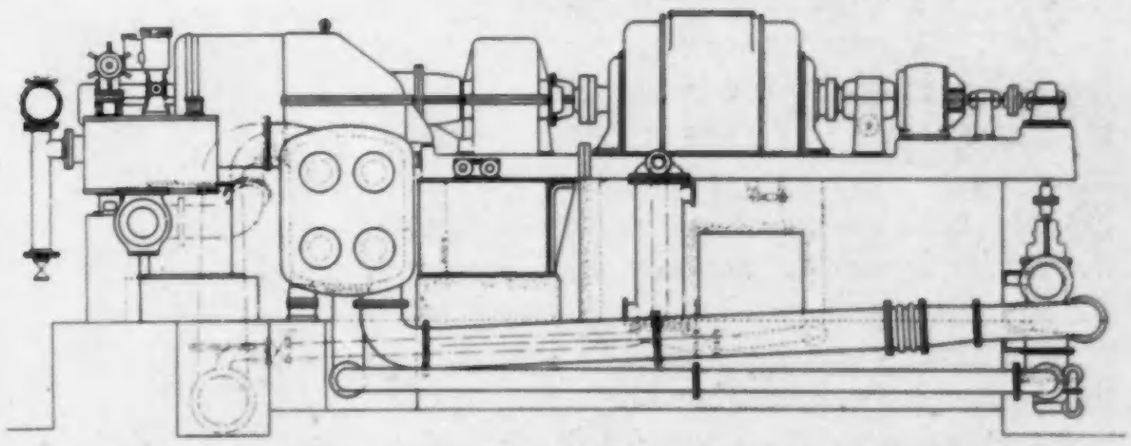

Fig. 22.—Combined turbine and condenser developed for installation in restricted spaces.

5. Larger surface on the lower spherical bearing has been obtained due to the new method of securing the connecting rod to the spherical end.

WINDING ENGINES.

More accurate and simplified control is being applied to winding engines. This is exemplified by

the method shown in fig. 23, which is applicable either to A.C. or D.C. machines.

The hand operated emergency, air failure,

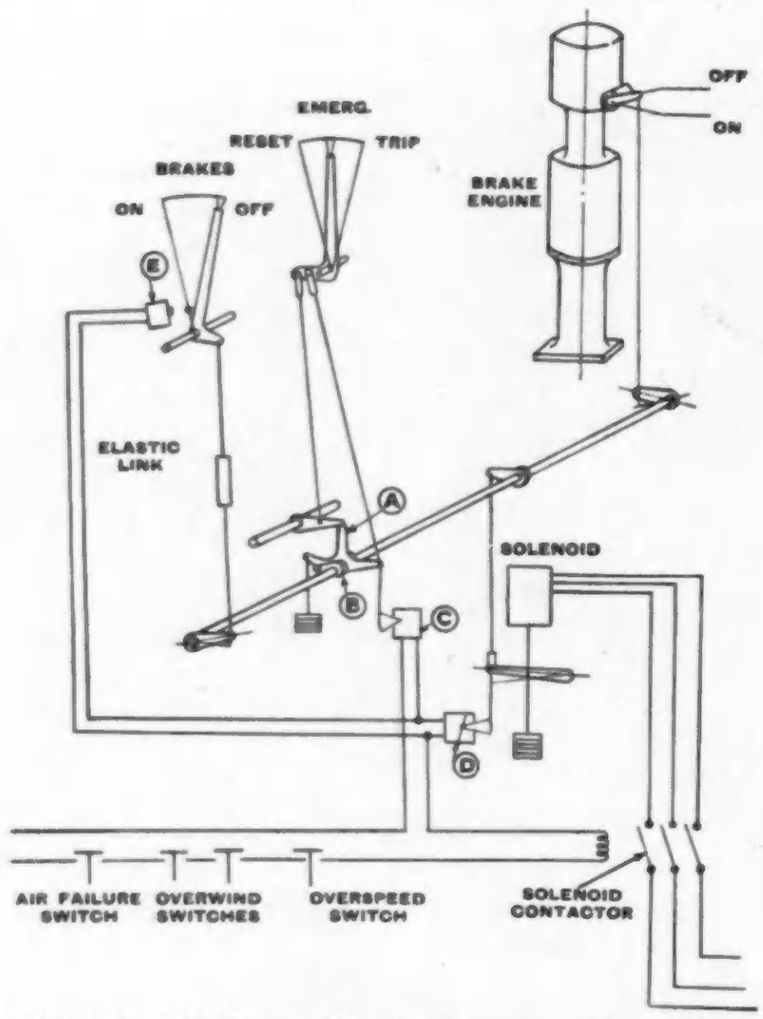

Fig. 23.—Diagram illustrating new simplified control of winding engines.

overspeed and overwind devices are all electrically operated and are in the same circuit. The operation of any of these opens the solenoid contactor and the solenoid opens the brake engine valve directly. This arrangement provides that the brake operating shaft is common to both normal and emergency working, and as the parts are in constant use there is little chance of failure in an emergency due to sticking. Another advantage is that when the solenoid fails the brake lever has a tendency to go "on" under the influence of the spring link. This was not the case with the old type of gear, and in some designs the brake lever was actually dis-connected. Finally, the whole gear is self re-setting when normal conditions have been restored, and the brake lever has been brought to the "on" position to close the interlock switch.

A further development relates to the mechanical operation of large liquid controllers. It is well known that where the control lever is connected directly to the controller, the manual effort required to operate is high. Moreover, the rate of acceleration is in the driver's hands due to the direct connection ; both of these conditions are undesirable as they throw very heavy work and undue responsibility on the driver, particularly in the case of large A.C. winders. This difficulty has been overcome by a device which both regulates the rate of acceleration and gives power assistance to move the controller. An arrangement of the device, for the operation of which power is derived from compressed air, is shown in figs. 24 and 25.

Cylinder (A), fig. 24, is the power cylinder and cylinder (B) is the regulating cylinder. The two pistons are connected together through levers and rods as shown and cylinder (B) is submerged in oil. When air is admitted to the lower end of the power cylinder, oil is forced out of the needle valve, so that the rate of movement of the piston is controlled by the setting of the needle valve. The pistons are connected to the controller so that the acceleration corresponds to the rate of movement of the pistons. The air supply is controlled from the driver's lever through the air valve, and floating lever mechanism, so that if the driver's lever is only moved half over the pistons travel only half-way. With this arrangement the driver can put the lever immediately from "off" to full "on," but the movement of the controller and therefore acceleration will be regulated by the needle valve.

When bringing the control lever back to "off" the movement of the pistons is not under the control of the needle valve, but the oil is drawn into the cylinder through the non-return valve. The return movement is consequently rapid and practically follows the driver's lever.

A third development comprises a power assistance

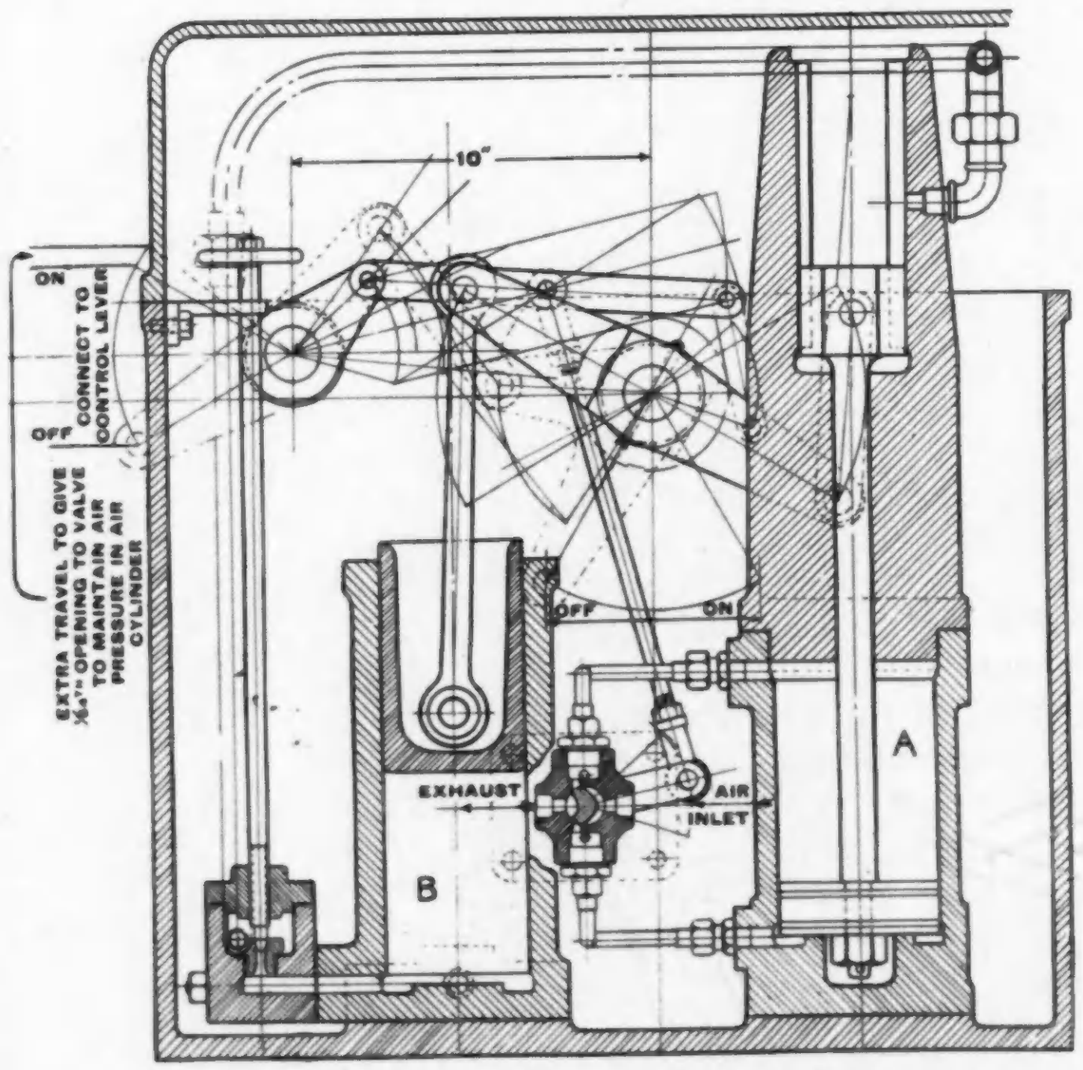

Fig. 24.—Section through device designed to regulate acceleration of winding engines and to assist the operator to move the liquid controller lever.

gear for operating large throttle valves in steam winding engines and is particularly useful in the case of compound winders where two throttles have to be worked.

The device consists of a double acting steam operated power piston controlled from a pilot valve, the two being connected together with a floating lever. The power piston is coupled directly to the throttles and the pilot valve to the driver's lever. To open or close the throttles the driver has only to operate the pilot valve, which relieves him entirely of heavy manual effort.

PULVERISED FUEL PLANT.

Investigation has been made into the problem of efficiently de-dusting coal at collieries and classifying the dust so that finer particles can be burnt on boilers without any pulverising plant. An installation applied to one boiler at a Midland Colliery was so successful that two further boilers at the Colliery were equipped, and shortly afterwards the management of a neighbouring colliery decided to instal the equipment for three boilers.

The output of the boilers equipped with pulverised coal can be increased considerably, thus allowing inferior or refuse coal to be used on the other boilers. The normal load can be met by the hand fired boilers and the pulverised fuel boilers used to meet the peaks and fluctuations, thus improving the efficiency of the whole boiler plant. Except on the smallest installation a material saving in labour can be effected, whilst on account of the simplicity of the plant the capital cost involved is low.

The system has many advantages. The value of the slack is increased by the amount of the fine dust,

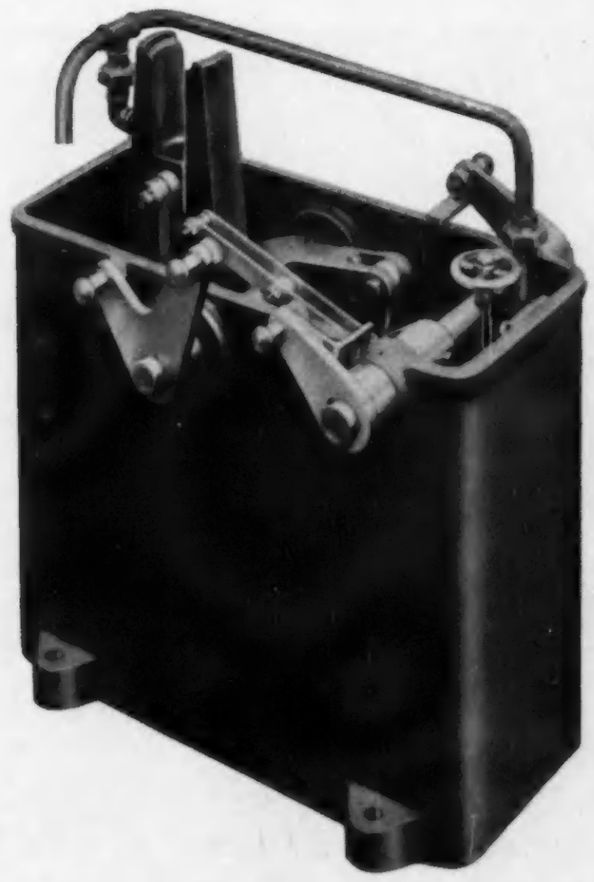

Fig. 25.—View of device shown in section in fig. 24.

or if a washery is installed slurry troubles are reduced to a minimum, whilst in either case the dust nuisance on the screens is eliminated.

MATERIALS HANDLING PLANT.

A wagon tippler, fig. 26, of exceptional capacity

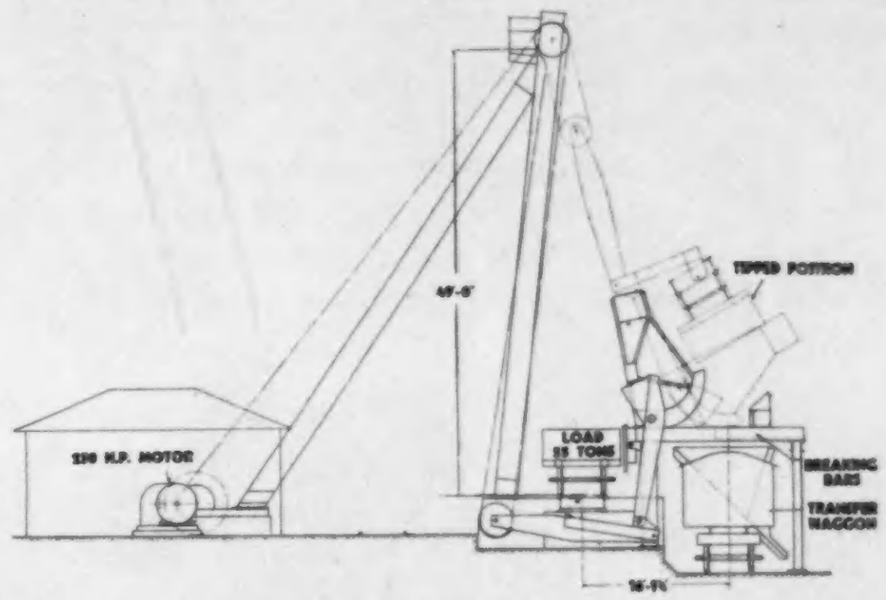

Fig. 26.—55 ton wagon tippler supplied to a Swedish Railway Company.

has been constructed for handling wagons of iron ore for a Swedish Railway Company. The wagons each contain 40 tons of iron ore and have a total weight of 55 tons. They are tipped at the rate of 40 wagons per hour. An unusual feature, and one that called for particular care in the design of the machine, is that the ore is frozen solid in the wagon during the winter months. It is thawed at the edge of the wagon before being tipped and therefore falls away in a solid lump of 40 tons weight. To break this up, cast steel V shaped ploughs are placed on the delivery plate.

Four special purpose machines, each consisting of a transporter for handling coal into ships, are being installed at Gibraltar. They have been designed to coal ships at the rate of 2½ tons to 150 tons per hour and each is provided with a steel telescopic chute to reach down to the small ships ; they are also able to slew and to move in several directions to suit the varying positions of ships bunkers. A most important and unique feature of the arrangement is an automatic weighing device which weighs and records all coal delivered over the loader. The machine is illustrated in fig. 27.

The manufacture of "Webb" overhead conveyors is being undertaken. An installation for handling manufactured parts through the stages of production in a wireless factory is shown in fig. 28. The principle of the application is of course very old, but modern developments in engineering production have enabled the use of such features as roller bearings and dropped forged links to be incorporated so that the principle is applied with greater efficiency.

The Redler Conveying System covers a complete range of conveying, elevating, measuring and blending

machines particularly suitable for dealing with powdered and granular materials, the handling of which by other types of conveyors often present considerable difficulties. A number of these machines have been built during the past year, with capacities ranging from 30lbs. per hour to 200 tons per hour. For some years, operating data on these machines as applied to the handling of admittedly difficult material has been obtained, with the result that the scope of the system has been considerably increased.

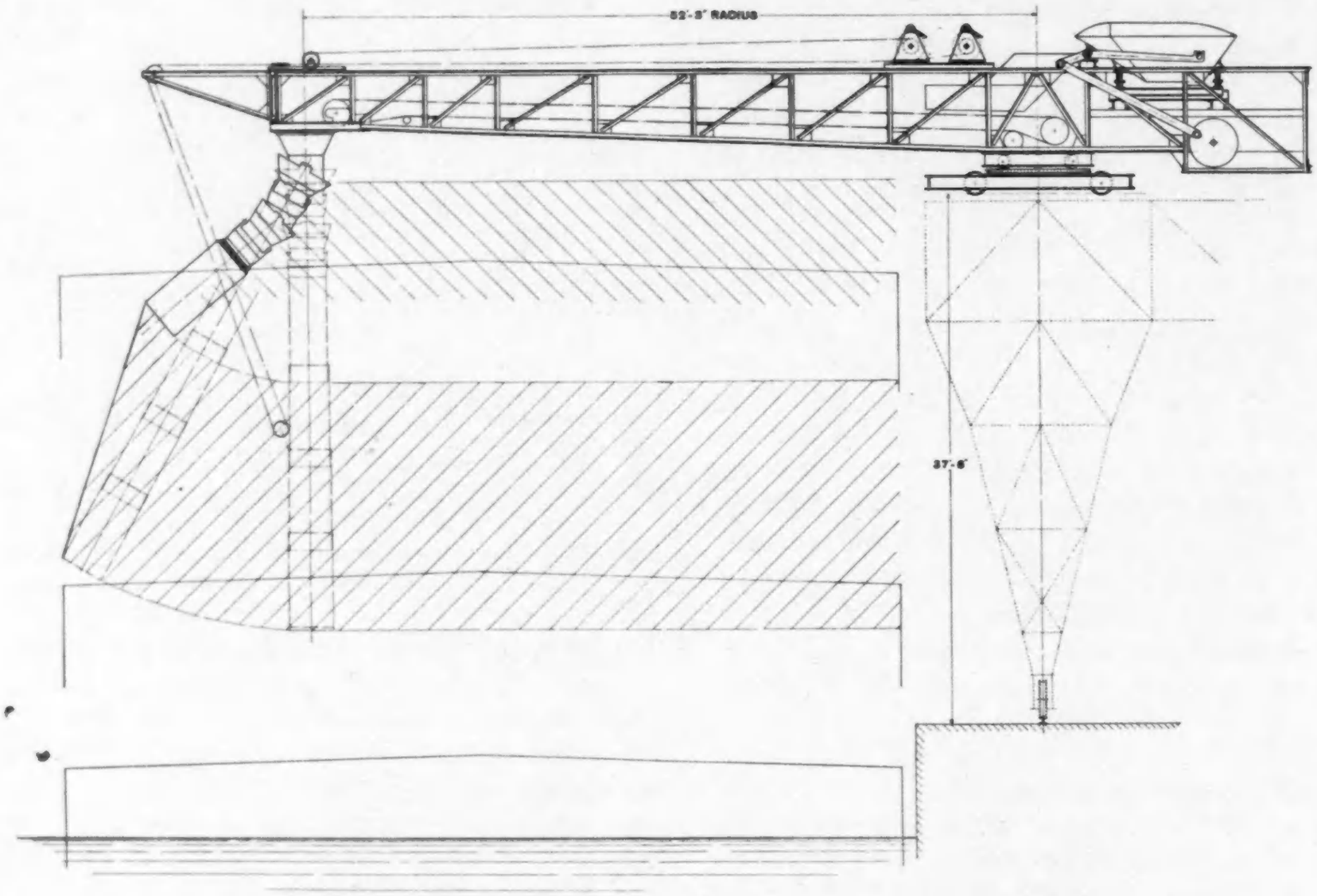

Fig. 27.—General arrangement of boom loader and telescopic chute.

Fig. 28.—"Webb" conveyor installed in a wireless factory.

MINING PLANT.

A new principle in vibrating mechanisms has been successfully applied to screening and concentrating tables. The vibrator is composed of one or more direct current solenoids, the cores or armatures of which are held in position by flat hickory or laminated steel springs. The screen live frame or concentration table is supported in a similar manner, which dispenses with all bearings. The natural frequency developed in the spring supported body governs the speed of the machine and can be con-

Fig. 29.—Sherwen screen, 18ft. long by 3ft. wide, screening coke into six different sizes.

trolled by means of a handwheel which, by compressing or releasing a spiral spring, varies this natural frequency, thus giving a short fast stroke or a long slow stroke at will. The intensity of vibration is also variable by means of a thumb screw which varies the time during which the coils are energised on each cycle.

The power consumption is very low due to the fact that contact is broken to the coils during each cycle thus the vibrator automatically synchronises with the natural frequency of the spring supported frame. This synchronisation makes possible the vibration of very heavy bodies at a speed and amplitude that could only otherwise be obtained with greatly increased power. An instance of this is a coke screen, the live screen frame of which is 18ft. by 3ft. 4ins. It is vibrated at 1,000 cycles per minute at quarter inch stroke and consumes only 1 h.p. The screens previously employed took no less than 8 h.p.

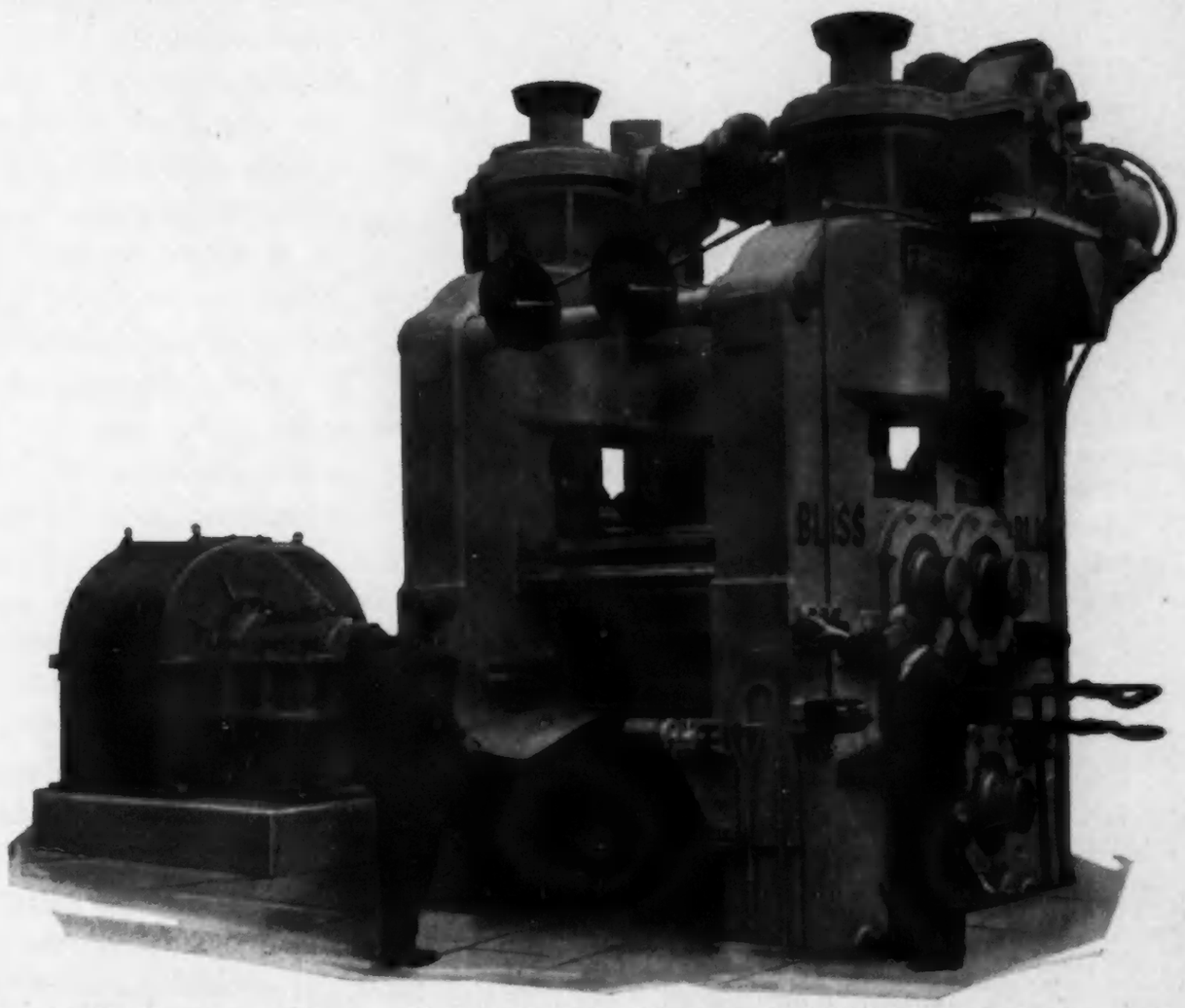

Fig. 30.—"Bliss" type rolling mill installed in Messrs. Baldwin's Steelworks at Stourport. The mill is driven through gearing by a 250 h.p. 100/500 r.p.m. D.C. motor operating from a 460 volt supply.

ROLLING MILLS.

The Bliss type Cluster Mill illustrated in fig. 30 was installed during the past year. Important improvements on the economics of sheet rolling practice have been effected, as it has been possible for sheets up to 50ins. in width to be rolled by cold rolling methods, with the attendant advantages of ductility and high polish, whereas by cold rolling on ordinary two-high mills sheets greater than 15ins. in width cannot be produced.

GAS CLEANING PLANT.

A development has been made in connection with the bag shaking gear in dry gas cleaning plants of the Halberg Beth type which overcome a disadvantage hitherto existing in plant of this type. In the process of cleaning the gas, dust is entrapped in the bags and they in time become choked. To clean the bags the flow of gas is reversed and the bags are shaken by a pneumatic shaking gear. This gear, however, had the disadvantage of being controlled from one point only and a particular or isolated filter compartment could not be given individual treatment, but had to be left to function, often inadequately, until the plant was shut down. The new development overcomes this disadvantage and enables any filter compartment to be treated individually at any time without relation to another. Moreover, it is possible to accentuate or vary the intensity of the vibrations given to the bags.

LAMPS AND ILLUMINATION.

Progress in the manufacture of standard lighting lamps has centred round improvement in the uniformity of the product, with the object of reducing the deviation of individual lamps from the mean in life, light output and efficiency. This subject was dealt with at some length in an article in the *G.E.C. Journal*, Vol. II, No. 3 ("Precision in Lamp Manufacture") so that detailed reference here is unnecessary. The practical outcome is shown in the much more uniform performance of Osram lamps in general.

Further improvements have been made in the processes of heat treatment applied to lamp filaments

both as part of the general effort for uniformity and as a means of producing that stability of the filament which is essential when it is important that the light source must retain its original position, as in the case of projector lamps.

Fig. 31.—Decorative lighting in the Borough of Hammersmith Electricity Showrooms.

An important improvement to certain high-wattage lamps (viz., 500, 1,000 and 1,500 watts) is that they can now be supplied for horizontal burning with a loss of only about 20 per cent in life, thus being suitable for stage lighting and flood lighting where lamps are frequently burned at abnormal angles.

Fig. 32.—Central auditorium fitting in the Metropole Cinema, London.

In view of the very large range of lamps already manufactured, comparatively few new types have been found necessary. Development has, however, proceeded in certain directions, *e.g.*, new types of large lamps of 3, 5 and 10 kW have been manufactured for cinema studio and aerodrome lighting. The principal aim has been to develop filament arrangements of the shapes best suited to give the desired light distribution.

Projector lamps of smaller types, employing light sources of only 5 millimetres square, have been developed for home cinema apparatus. These lamps, rated at only 50 watts, are constructed with filaments made on the coiled-coil principle which provides the extraordinarily small projected light source referred to, notwithstanding that the lamps are rated at 115 volts. Other special types of projector lamps have been produced for similar apparatus.

A new type of Osglim Indicator lamp, intended more particularly as an indicator in connection with Magnet industrial heating and cooking apparatus, possesses the feature that, notwithstanding the almost negligible consumption of the lamp (under 1 watt), a luminous indicator with a light source about $\frac{3}{4}$in. square is provided for use on normal voltages.

An Ultra-Violet lamp is another new departure. It is designed with a very short, thick tungsten filament connected across the lead-in wires, which lead-in wires also carry arc electrodes. The bulb contains a pool of mercury which is vapourised when the filament becomes incandescent and enables a mercury arc to be struck up between the electrodes, the arc operating in parallel with the filament. The bulb is made of special glass which transmits, with very little absorbtion, short-wave radiations between 2,800 and 3,300 angs. The mercury arc provides a light source particularly rich in ultra-violet radiations, which are present in natural sunlight but practically absent from all ordinary artificial sources of light.

The tendency of illumination is towards more scientific methods of light control, particularly in relation to ornamental fittings. In the past, such places as hotels, theatres, public buildings and large stores have been illuminated by fittings of ornamental design containing a greater or less number of lamps merely concealed behind the necessary glassware; to-day such ornamental fittings embody interiors scientifically designed to ensure the maximum distribution of light in the direction in which it is required.

Simultaneously with this tendency towards the more scientific use of light, there has been a move towards greater use of concealed lighting systems

and systems embodied in the main structure of buildings in the form of laylights, wall lights, column lighting and the like. This development of architectural or decorative lighting has made rapid strides during 1931.

Architects till recently seldom considered schemes for artificial illumination until the decorative treatment of the interior of a building had been completed. This outlook has undergone rapid transformation and architects are recognising the possibility of obtaining decorative effects by means of light. Lighting fixtures now form an integral part of the architectural treatment of the interior and, as such, have as much relation to the whole conception as a door or a window.

Architectural features such as the architraves of doors and windows, cornices, beams, capitals of columns, and even the columns themselves are built up of glass and illuminated, but it is important to recognise that such features are frequently only luminous decorations and not sufficient in themselves to provide adequate illumination to meet requirements.

In the preparation of schemes no hard and fast line can be drawn between "luminous decoration" and "decorative illumination." Results of a satisfactory nature can, however, be assured by means of collaboration between the illuminating engineer and the decorative artist from the initial stages of architectural planning.

The present trend in the design of electric lighting units is in the direction of increased utilization of glass as a light diffusing medium. In earlier years when economy in current consumption was a greater consideration, metal work was chiefly relied upon for decorative effect, but the decreasing cost of current has led to decorative glassware forming the predominating feature of lighting fixtures. Care should, however, be shown lest the elimination of metal work goes to extremes. Modern designs are apt to be fragile, and a discriminate use of metal work in the construction of units is therefore desirable.

Certain of the principles touched upon in the foregoing paragraphs are illustrated in figs. 31 and 32, also in various views of the Q.T.E.V. "Monarch of Bermuda," described on page 48 of this issue.

Many cathedrals and churches have been illuminated by the G.E.C. in a manner worthy of their many beautiful architectural features. Ripon Cathedral affords a striking example, as may be seen by reference to the view of the choir stalls (fig. 33). In the nave, some units had to be concealed as much as 95ft. above pew level, and problems of wiring in addition to those of illumination had to be solved.

Picture galleries demand illumination of a highly specialised character; schemes for certain galleries of the National Gallery have been successfully carried through.

Fig. 33.—Concealed lighting in Ripon Cathedral.

Fig. 34.—A hospital lighting fitting designed to eliminate shadows. It will be seen that no shadow is cast by the operator who is holding his hands between the light and a table.

A shadowless fitting for hospital operating theatres is supplying a long felt need. The pattern

shown in fig. 34 is of a type supplied after exhaustive tests, for all hospitals, both at home and abroad, which come under the jurisdiction of the British War Office.

One of the most interesting of a number of new fittings for film studio lighting from overhead

Fig. 35.—Day view of the Municipal Gardens at Southend-on-Sea.

consists essentially of 20 matt aluminium reflectors mounted on a metal framework, each containing a 500 watt Osram lamp. The fitting may be tilted at various angles by means of gearing operated from the studio floor by an endless sashcord.

Another new unit is a 2 kW projector fitted with an 18in. diameter parabolic mirror and employing a special 2 kW lamp with a very small bulb. In order to prevent crackling noises due to expansion, which occur when sheet metal is used, the body of the projector is cast in aluminium alloy which makes it light and rigid. A large number of these new projectors and lamps have already been installed in film studios.

Street lighting progress has been marked by the completion of a full range of non-ventilated street lighting lanterns of the "Wembley" pattern from 60 watt up to 1,500 watt sizes, and the design of a range of refractors of a new and improved type in symmetric, asymmetric axial and asymmetric non-axial patterns to cover the above ranges. Attention has also been paid to the design of an inexpensive pattern of street lighting fitting suited for the requirements of the export market; two thousand of these fittings are being supplied for the lighting of the streets of Athens.

Floodlighting was referred to at the beginning of this article. A large amount of equipment for floodlighting notable buildings has been provided. Amongst these reference should be made to Buckingham Palace, Thames House, the Headquarters of the Institution of Electrical Engineers, Marischal Hall, Aberdeen, and the Carreras Factory, Islington. The last mentioned is of great importance, being the first of its kind in this country for which two colour lighting with automatic dimming control was employed. The total load required by this installation was 240 kW.

A radical departure from previous types of aerodrome floodlighting units is found in a new 9 kW landing floodlight mentioned earlier in the article in connection with the work of the Research Laboratories. It comprises three trough reflectors of parabolic contour mounted one above the other in a steel frame-

Fig. 36.—The same view by night.

work, each containing 1,000 watt tubular horizon lamps. The adjustment of the lamps is performed by an optical method so that their line filaments are at the foci of the reflectors, and the beam of light produced is fan shaped, *i.e.*, with very wide horizontal and very narrow vertical divergence.

The floodlight may be rotated on a turntable and each of the three tiers may be tilted separately or all three tiers together. Each lamp is provided with a separate switch and the arrangement of the floodlight makes it suitable for running off a 3 phase supply.

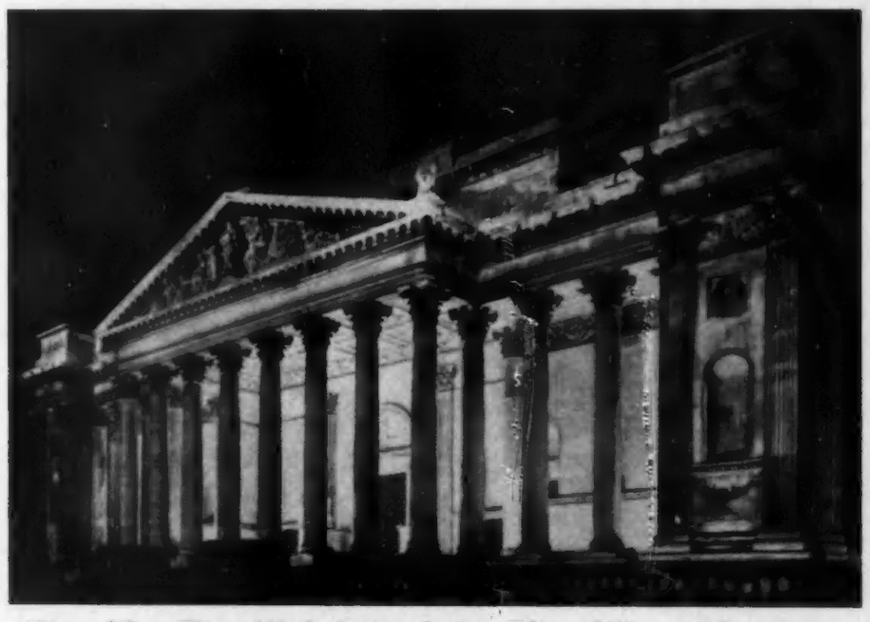

Fig. 37.—Floodlighting of the Fitzwilliam Museum, Cambridge.

The new floodlight has been used with great success at several aerodromes and one is now permanently installed at Ratcliffe Aerodrome, Leicester.

Developments have also taken place in the design of illuminated wind direction indicators for showing airmen the direction of the wind by day or night. A special indicator for the Air Ministry for installation at Lympne Aerodrome is in course of construction. This consists of a metal T, 20ft. long with a 12ft. cross piece mounted on a steel pivot. It is fitted with a streamlined fin directly operated by the wind, together with damping gear. The upper surface is equipped with lamps for making the T visible by night. Work has been carried out on boundary and obstruction lights with the result that the Air Ministry has been supplied with the first set of electric boundary lights to be used in this country. Each unit is complete with transformers, etc., and operates on the constant series potential system. The general arrangement of this apparatus is shown in fig. 40. A number of 3 kW flashing neon beacons for use at airports are in course of manufacture, while an air route beacon embodying a 3 kW lamp is in the experimental stage.

Fig. 38.—Lighting of Clydebank, Glasgow.

Fig. 39.—Aerodrome landing floodlight ; view shows landing area as seen by pilot.

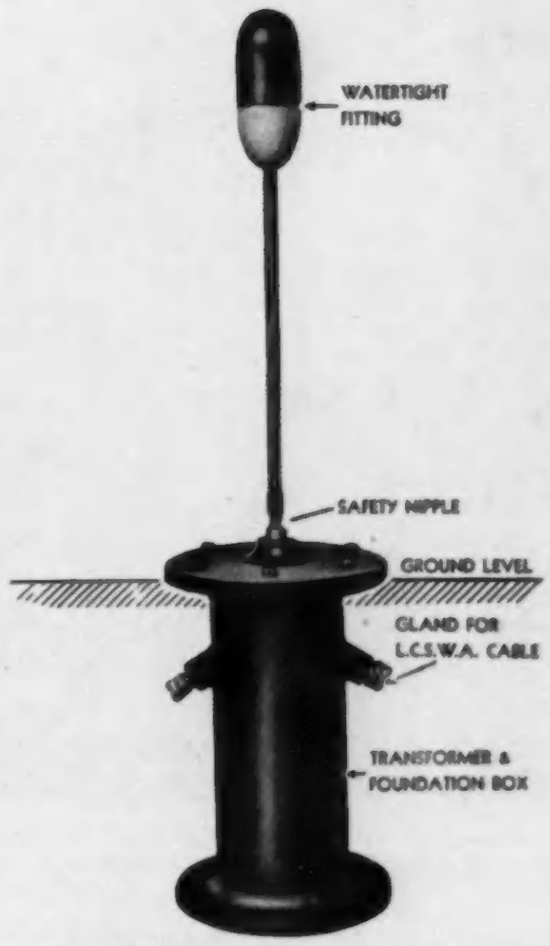

Fig. 40.—Electric boundary lights as supplied to the Air Ministry.

The use of neon signs is continually increasing and the range of colours available has been extended

to include gold, white and salmon pink. Improvements in technique have led to considerably lower operating voltages, and 2,500 volts to earth is now employed, whereas till recently, 10,000 or 12,000 volt transformers were required for operation.

Fig. 41.—Auto-manual switchboard at the Midland Mechanical Tandem Exchange, Birmingham.

The reduction of the sizes of electrodes and the method of concealing them represents another advance in design. The higher standards of glass blowing which exist to-day have contributed in no small measure to the successful developments of neon signs.

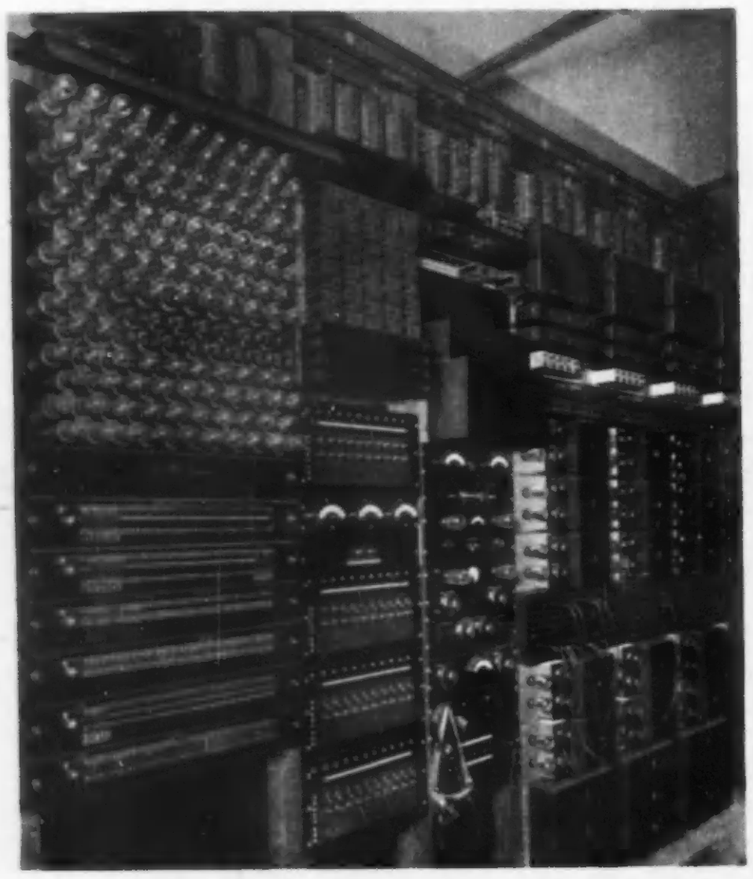

Fig. 42.—Typical repeater equipment at Canterbury, serving Anglo-Continental trunk telephone lines.

Before leaving the subject of illumination it is very gratifying to be able to record that great advances have been made in Great Britain during the year in the manufacture of illuminating glassware, whether in the form of mirror glass reflectors, prismatic refractors and similar glasses, or heavy pressed front glasses for floodlights.

TELEPHONES AND TELEPHONE EQUIPMENT.

During the past year the number of telephones in this country has passed the two million mark.

From the technical point of view the improvement in apparatus for automatic telephone working and its method of application has been most marked. Radical alterations in the construction of automatic exchanges have had as their object the standardisation of simplified units.

The first public automatic exchanges installed in Birmingham are an example of modern practice in the methods of serving a large densely populated area. Four local exchanges and a central mechanical tandem equipment have recently been completed and form the beginning of a Director system similar to that employed in London. Perhaps the most notable feature of the system is the introduction of straightforward junction working for calls coming into the automatic network from manual exchanges, a scheme whereby the "B" operators at the automanual switchboard (fig. 41) are enabled to handle a much greater volume of traffic. The local equipments now in service are designed for an ultimate total of over 20,000 subscribers' lines and will be followed by the installation of others throughout the complete area covering approximately 160 square miles.

In London where the conversion of the telephone system from manual to automatic is now at an advanced stage, progress is being made with the new Kensington Automatic Exchange which is to have a capacity of 10,000 lines. Tandem equipment for the automatic routing of inter-exchange calls in the west London area will be installed in this exchange.

As a result of new schemes for the improvement of the trunk service a large amount of work has been involved in the design and provision of thermionic repeaters for use on long distance circuits. New equipment has been installed at many points on the trunk network in Great Britain, and has also been supplied to various overseas administrations. Examples of the application of G.E.C. repeaters are also to be found in Iraq where new works are in progress on the Basrah-Baghdad route, and in East Africa on the trunk lines between Mombasa and Nairobi.

Of topical interest is the installation in this country of special underground lines to be given over to the transmission of programmes for the

British Broadcasting Corporation. For this class of service, a new type of repeater has been supplied which is designed to handle a range of frequencies much wider than that needed for the commercial transmission of speech only.

Activities other than those concerned directly with the public telephone service have grown considerably. Communication systems to meet the requirements of transport undertakings are, for instance, far in advance of what they were even two years ago. An interesting example is the new selective ringing telephone system for railway traffic control, which is fully described in the *G.E.C. Journal*, Vol. 2, No. 1 ("A Traffic Control Party Line System with Selective Calling by Dial.") The first installation of this kind has now been completed by the London and North Eastern Railway, fig. 43, and serves to bring under the control of an ordinary telephone dial a large traffic area in the North East of England.

Fig. 43.—District traffic control office of the London and North Eastern Railway at Darlington.

Of a somewhat different nature is a speech transmission system installed on a section of the London Underground Railways, and intended ultimately for extension over other routes. The object in this case is to "broadcast" sumultaneously to all booking offices immediate instructions relating to emergency traffic arrangements in the event of breakdown. Loud speakers are provided at each point and the whole system is controlled from a centrally situated switchboard and microphone. In the design of the circuits many new features have been incorporated, notably a delayed switching device employing neon tubes.

The increasing application of telephone types of apparatus and the value of co-operation between individual branches of the electrical industry, are clearly to be seen in the rapid development of various schemes for the centralisation of control of sub-stations on power networks. Progress in this connection has enabled equipments to be manufactured for the supply of remote control gear for sections of the "Grid" and for local power systems both at home and abroad. Under this heading may also be included the application of "carrier" systems to e.h.t. transmission lines for telephone and supervisory purposes and for feeder protection. Where independent lines are employed, over which communication and remote indication facilities are to be provided, voice frequency signalling has been introduced for use on long circuits.

Carrier apparatus is being more widely employed for providing additional speech channels over ordinary telephone lines, and considerable progress is to be recorded in the design of both circuits and equipment for this class of service. The economy effected by superimposing a "wired wireless" system on an existing long distance circuit is such that extensive developments in this field are likely to be seen in the near future.

Plans were recently drawn up by the British Post Office for the construction of a new telephone trunk system by which it would be possible to obtain trunk telephone calls over a large part of the country "on demand" in much the same way that local calls are now obtained. This system is known as the "Demand Trunk Service" and the technical requirements are in many ways different from those of present main telephone lines, the new service requiring entirely new kinds of telephone cable, repeaters and loading coils.

Fig. 44.—Automatic telephone equipment at the new telephone exchange, Nairobi, Kenya.

The possibilities of producing a new type of

loading coil and loading pot specially for loading of aerial cables have been investigated, and as the results were promising, the whole of the loading of the experimental minor trunk circuit between London and Brighton was undertaken by the G.E.C. for Post Office requirements. The tests carried out by

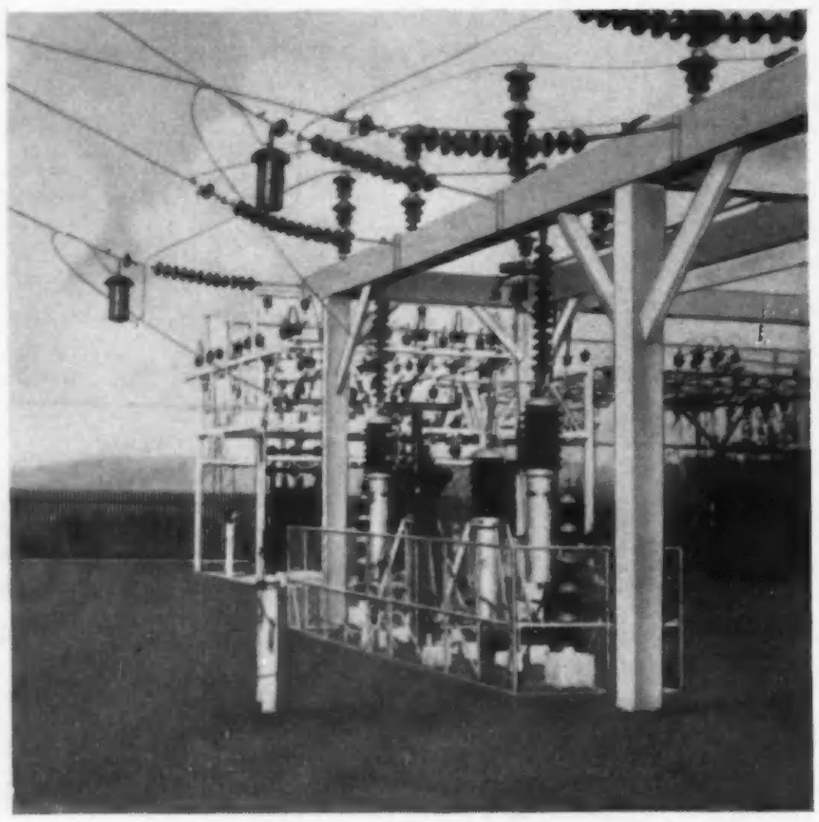

Fig. 45.—132 kV outdoor switching station showing carrier choke coils and coupling condensers.

the Post Office Engineers on the system after it had been completed gave thoroughly satisfactory results.

Mainly for economic reasons, aerial cable is used for the whole of this line, except where the density of population renders the familiar underground construction essential, and for this purpose a special type of cable was produced. Each conductor was of 10lb. weight per mile, or one quarter of the size of the usual trunk line, and the cable consisted of 74 pairs in the small compass of one inch overall diameter, including the special lead-alloy covering.

The loading problem consisted essentially of arranging for 74 inductances of quality approaching in many ways that of underground loading coils, to be assembled in a pot of extremely light and weatherproof construction, and of sufficiently small size to be installed on a telephone pole. The degree of success which attended the solution of this problem from the point of view of size is well illustrated in figure 46. The extent to which the lightness requirement has been met is demonstrated by the ratio of the weights of the pots, which is approximately 7—1.

The size and shape of the pot facilitates the handling and installation, which are correspondingly more difficult high up on a telephone pole than in a manhole under the road; the wind resistance and danger from accumulation of ice and snow in storms have been reduced to a minimum.

In the world of broadcasting the year has been notable chiefly on account of the increase in the number of high power transmitters operating in Europe. The consequent congestion of the ether still remains a vexed question but, fortunately for the listener, improvements in radio receiver design have made possible more efficient and highly selective instruments than formerly. While technical progress has been largely bound up with valve developments a variety of new features have been introduced both in the design of complete receivers and in the construction of loud speakers and accessories.

Of the many new receivers introduced, reference may be made to an entirely new departure, namely, a colonial model for service where the main source of news and entertainment is the short-wave programme. This is a six valve superheterodyne set giving a very wide range and high degree of selectivity. Component parts have been greatly simplified and materials and finishes have been selected with a view to ensure reliability and long service under adverse climatic conditions.

The attempt to bring radio entertainment within reach of the man of very limited means has led to the installation in many towns of relay systems for the redistribution of broadcast programmes over land lines. Such schemes permit of a very low service charge and limit the subscriber's equipment to a loud speaker tapped across the two lines serving his district. Methods have been evolved for the automatic remote control of sub-amplifiers serving groups of subscribers situated at a distance from the main receiving station.

TELEPHONE CABLES.

Reference was made above to the development of loading coils for aerial cables required for "on demand" trunk service. The decision to extend this form of service has resulted in considerable modifications to the design of trunk cables, lighter gauge conductors being required for four-wire repeater working. Rural extensions have led to still further modifications in design, and as aerial cables having 10lb. conductors were required, a 74 pair 10lb. star quad aerial cable (referred to above) was made for the Post Office, this being the first cable of its type to be manufactured.

During 1931, considerable modifications to many of the machines in the Eastleigh factories were effected in order to meet the demands of the British Post Office for new type trunk cables to increasingly severe specifications.

Reference was made in the *G.E.C. Journal*, Vol. 1, No. 4 ("Electrical Progress and Development 1930") to the experiments being carried out by the Post Office with a view to replacing the old type subscribers' twin cable with star quad cable. These

experiments have been so far successful that to-day the old type twin cable is obsolete.

It is not important that the subscribers' star quad cable should have the same uniform electrical characteristics as the trunk star quad cable, but it has been necessary to design high speed machines to manufacture this type of cable at a price comparable with the old twin cable. During the year considerable progress has been made, and although the design of the factory equipment has by no means reached finality, some high speed machines have been installed and the new type of cable is being produced commercially.

POWER CABLES AND TRANSMISSION LINES.

Developments in underground power cables have been chiefly in the super-tension field and notable progress has been made in simplifying both the manufacture and installation of oil-filled cables. A large quantity both of 33 kV and 66 kV cable of this type is being manufactured and installed for the Central Electricity Board. At the beginning of the year approximately 26 miles of oil-filled cable and in October 36 miles of 132 kV oil-filled cable were placed in service.

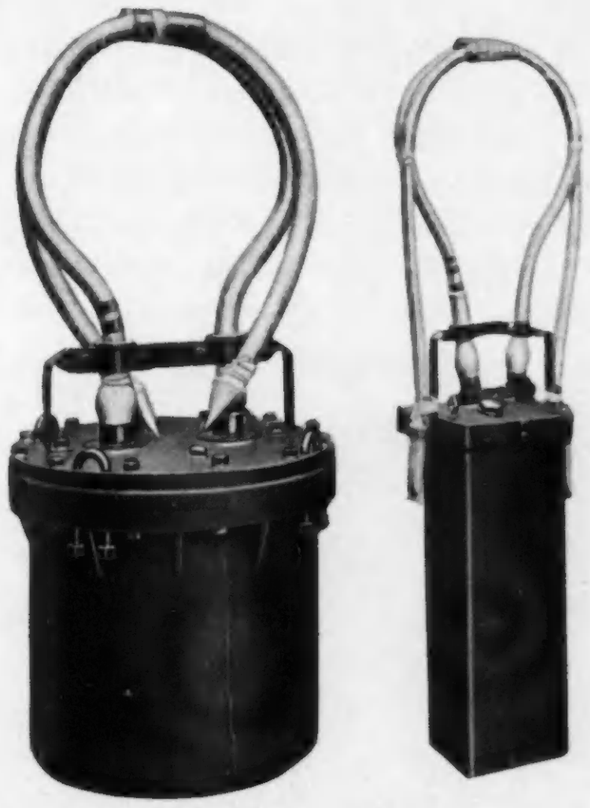

Fig. 46.—Comparison of the relative size of pot to accommodate equal numbers of loading coils for underground and aerial working.

It is interesting to note that the principal cable firms have become licencees under Pirelli patents for the manufacture of oil-filled cables.

Other important work in hand includes that for the main line electrification scheme of the Southern Railway Company, which is the first main line scheme in England. Cables are of the three-core lead sheath type for a working pressure of 33 kV and are at present being installed between London and Brighton, a distance of approximately 52 miles.

The tendency in overhead transmission line work has been in the direction of standardisation rather than development of new equipment. The various types of equipment now put forward as standard cover all normal requirements. A minor modification in e.h.t. wood pole equipment has, however, been standardised during the year. The type of earth bar now employed has the advantage of fitting on the standard pole equipment, usually without any necessity for additional securing bolts in the pole; an efficient bonding of the earth bar is therefore assured while the need of a separate bond is eliminated.

A development in conductors for lines of small electrical cross section has been patented (patent No. 344194) and employed to a considerable extent. This conductor is composite, consisting of both "copperweld" and copper strands. Normally a central "copperweld" wire is surrounded by a layer of copper wires and the resulting conductor has a high mechanical strength as compared with an equivalent copper conductor, thus enabling longer spans to be conveniently employed. There is no risk of electrolytic action due to dissimilar metals in contact and the liability to corrosion is no greater than with plain copper conductors. Special joints have been developed for use with this conductor and have shown satisfactory results under test.

An attempt has been made during the year to produce a convenient tool for the purpose of enabling defective tension insulator units to be replaced without the necessity of lowering the complete string to the ground and re-tensioning the line. A device of this kind has been developed and tried out with satisfactory results. There are certain difficulties owing to the variety of designs of insulator unit, but it is hoped to place a tool on the market shortly which will be readily adapted to all normal types. The cost and delay involved by maintenance work on tension insulators, particularly on heavy lines, will be very appreciably reduced by means of this tool.

INDUSTRIAL HEATING.

The application of electrically created heat to industrial processes did not seem to make great headway until comparatively recently. But few branches of the electrical industry made greater progress during 1931 whether regarded from the point of view of new applications and methods of application, or from the standpoint of the number of installations completed and the increasing capacity of ovens and furnaces.

As recorded in the *G.E.C. Journal*, Vol. II, No. 3 ("The Heat Treatment of Steel") one of the most important methods developed is that known as nitrarding, a process applied to the surface hardening of special steels. Nitrarding furnaces are of two types, the usual rectangular box or batch type fitted with

special roller hearth, and the vertical cylindrical type. The range of sizes available in these types covers the whole field of nitrarding, and standardisation enables a furnace exactly suited to any size or shape of product to be provided.

A range of disturbed-atmosphere furnaces for such purposes as tempering and nitrarding steel has also been developed. So far as tempering and other low-temperature processes are concerned, the mechanical disturbance of the furnace atmosphere facilitates and accelerates heat exchange, resulting in the attainment of a uniform temperature throughout the charge in a relatively short period of time.

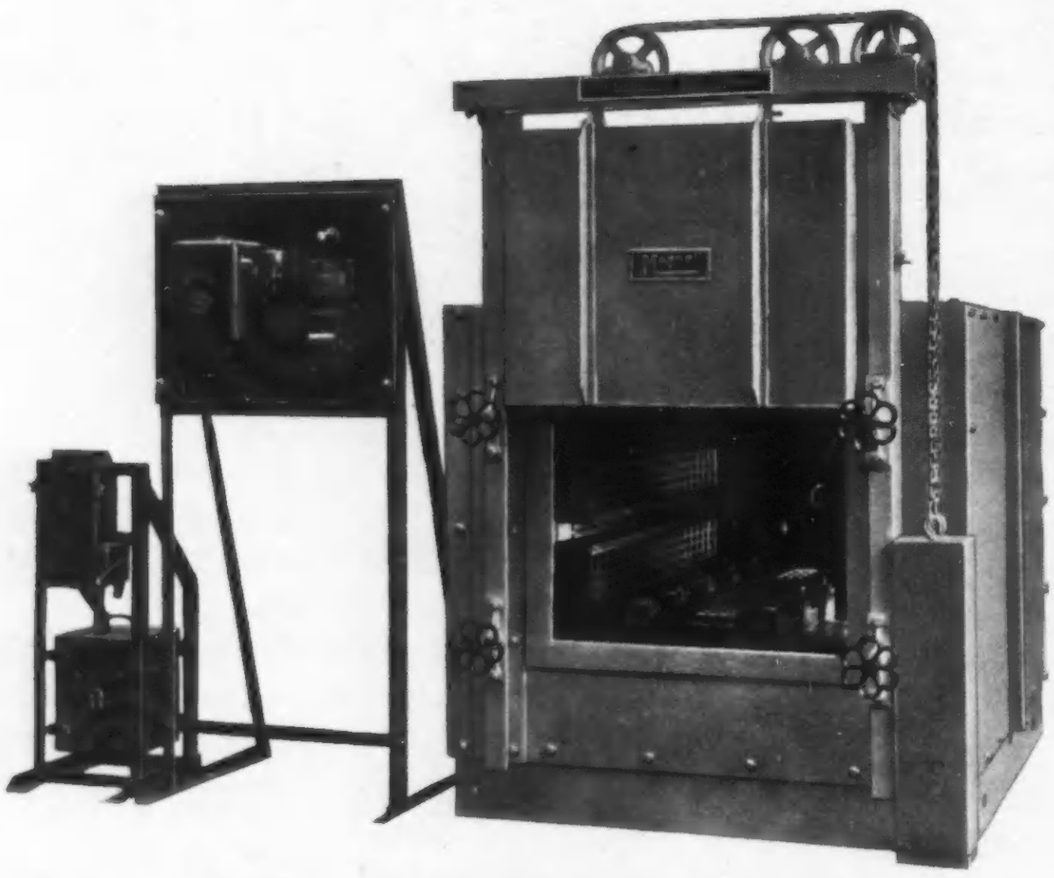

Fig. 47.—12 kW "Magnet" furnace for nitrarding by the Nitralloy process. This furnace, which is installed in the works of Messrs. Sheepbridge-Stokes Centrifugal Castings Co., Ltd., accommodates a "Magnet" nitrarding box with internal dimensions 47ins. long by 20 ins. wide by 14ins. high and has a holding capacity of useful charge of about 6½ cwts.

When applied to nitrarding, this feature ensures that every part of the surface of the pieces being treated is brought into intimate contact with the ammonia gas within the box.

A notable installation completed during the year is a 250 kW electric furnace for vitreous enamelling. It is 12ft. long by 4ft. 6ins. wide and 4ft. 6ins. high, and possesses important and novel features of design.

A vertical cylindrical furnace for melting glass for tube manufacture has been in operation on a commercial scale for several months and is proving eminently successful. This is the first electric furnace of its kind.

Interesting information is now available concerning a heat treatment installation for special steel magnets. The equipment consists of three standard furnaces each having internal dimensions 21ins. wide by 17ins. high to the spring of the arch, by 44ins. long. Each furnace is rated at 30 kW on 230 volt single phase a.c. supply, and is controlled by regulators working on the thermo-electric principle. Close temperature control is absolutely essential for magnet hardening as small variations appreciably affect the magnetic properties; every magnet is, therefore, tested for any falling off in this property.

The output per furnace is approximately 100lbs. per hour, and two operators and a youth are capable of keeping all three furnaces in continuous operation. A 22-hour day is worked, and it is estimated that to obtain the same output under the old conditions, at least ten operators would be required. The labour cost is no more than 0.15d. per lb. The usual temperature is 1,000 deg. Cent. although occasionally 940 deg. Cent. is used, and on continuous running a consumption of approximately 5lbs. per unit is being obtained.

The application of electric furnaces for non-ferrous metals is extending, and several installations have recently been put into operation. One of these comprises a 150 kW furnace and has an effective hearth area of 7ft. 5ins. wide by 24ft. long. It is used for annealing aluminium in sheets of various thicknesses. The furnace is a car bottom type, equipped with six cars, four of which are always in the furnace. Resistors are arranged in the roof, on each side wall, and also in the hearths of the car, special pick-up gear being arranged underneath the cars.

A very different type of furnace has been designed for the annealing of fine gauge phosphor bronze wire. The furnace chamber is filled with 120 tubes of ¼in. bore by ½in. outside diameter, and through each, a single strand of wire is continuously drawn. Four of these furnaces are at present in operation, and very good results are being obtained. Low temperature applications have also made progress as exampled by furnaces for coil drying, japanning and enamelling.

An excellent example of heating on the electric thermal storage system was recently completed. The original radiator system is coupled up with a new radiator system in office extensions, the completed system being pump-fed from the thermal storage tanks. The "boiler" house equipment consists of two lagged welded steel tanks each of 3,000 gallons capacity. Each tank is fitted with four nests of heaters embodying standard withdrawable heating elements. The total load of the system of 200 kW is controlled thermostatically to a maximum temperature of 220 deg. Fahr. and the four thermostats which are embodied operate special contactors mounted on the main switchboard. The

whole system is subject to time switch control and current is available for nine hours in the night only, except that a one hour boosting period at mid-day may be taken advantage of under certain conditions. By the incorporation in the system of a standard type automatic mixing valve a flow temperature to the radiators of 160 deg. is ensured. From the economic point of view a feature of this installation is that excavations had to be carried out for the housing of the tanks and auxiliary apparatus, but in spite of this added expense the system is giving satisfactory results.

Industrial electric cooking ovens are gaining ground throughout the country, this remark applying equally to bakery ovens. It should be recorded that a "Magnet" pastry oven was awarded the Gold Medal of the Royal Lancashire Agricultural Society. The possibilities of electric cooking are very well illustrated by the galley equipment on the Q.T.E.V. "Monarch of Bermuda" which is fully described on pages 51–53 of this issue.

DOMESTIC ELECTRIC COOKERS.

Of great interest has been the development of an electric storage cooker with constant loading which has been produced in an endeavour to increase the scope of domestic electric cooking. Many problems associated with the design of this cooker were successfully surmounted by the Research Laboratories. It is intended particularly for use in rural areas and other districts where the use of ordinary electric cookers is impracticable. The property of

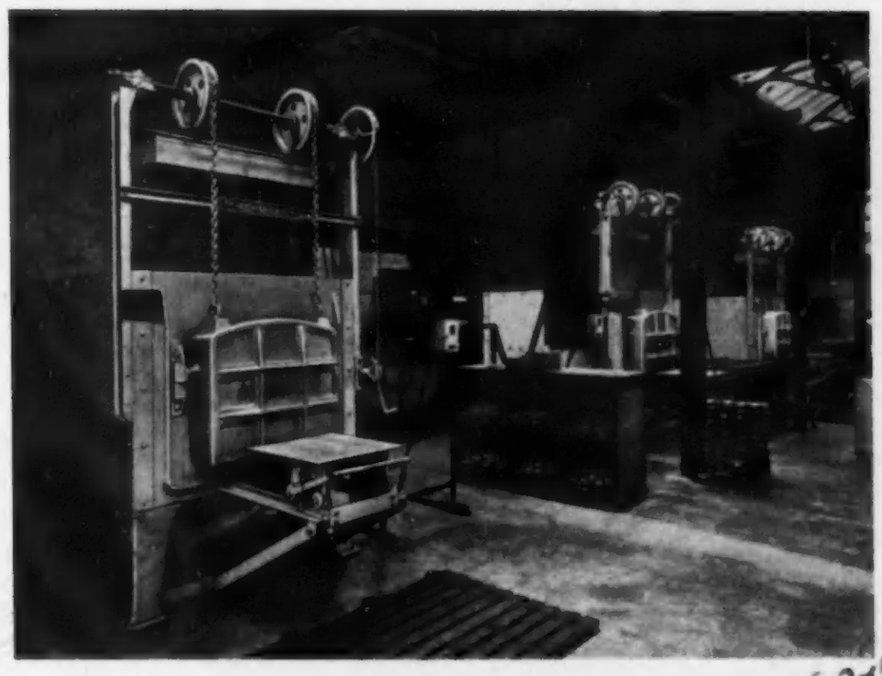

Fig. 48.—Three 30 kW "Magnet" furnaces hardening magnets in the works of Messrs. Darwins, Ltd. of Sheffield. Internal dimensions of the furnaces, 44ins. long by 21ins. wide by 17ins. high.

constant loading should enable supply companies to quote a special tariff.

As a further simplification it is probable that in a majority of cases the energy will not be metered, and the cooker will be hired out by supply companies at a rental to include both energy and the use of the cooker itself. Sample cookers have been sent to various engineers all over the country for test purposes, and their reports indicate that there is a definite market for a cooker of this type and that the performance of this model is satisfactory.

The main constructional feature of the cooker is a block of iron weighing 130lbs. in which are embedded two removable immersion heaters having

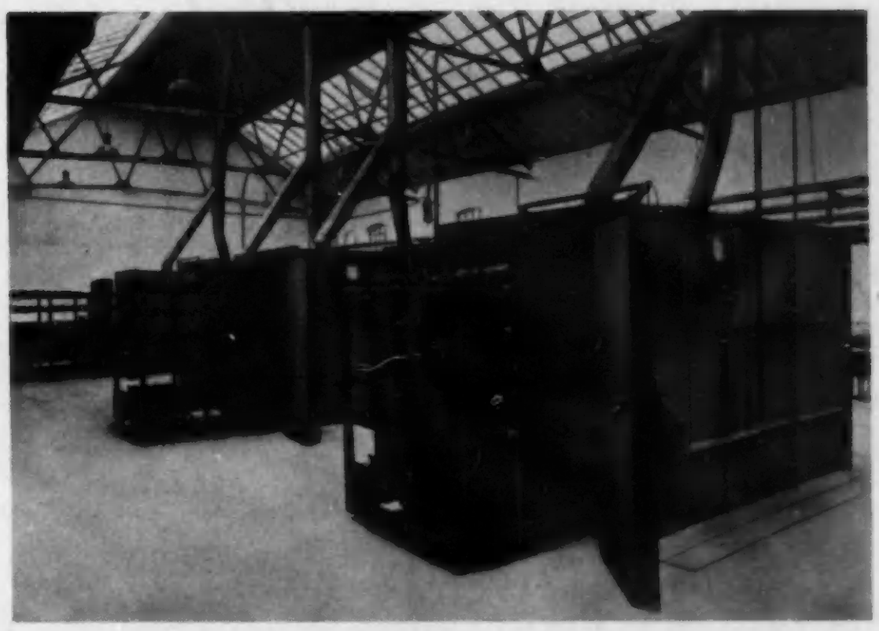

Fig. 49.—Four 54 kW "Magnet" electric japanning ovens installed in a Midland steel conduit works, each capable of treating 2,000 mixed conduit fittings per charge. Internal dimensions, 9ft. 8ins. by 5ft. 6ins. by 6ft. 6ins.

a total loading of 500 watts. The top surface of the block serves as a boiling plate and its lower surface as a top oven heater, transference of heat in the latter case being controlled by means of a deflector plate. In the bottom of the oven is an additional heater having approximately the same total loading as the block heater, and the two heaters are controlled by means of a changeover switch so that only one can be in circuit at a time thus maintaining the constant loading.

It is gratifying to record the success of a new series of electric cookers for the overseas market. The demand for these has made an important contribution to the total number of domestic cookers produced, which is double that of the previous year.

Continual investigation into questions affecting the design of "Magnet" totally enclosed hot plates has resulted in a product of wide utility. The range of hot plates has been extended to include sizes suitable for installation in all principle makes of domestic cooker, and the manufacturing plant has been greatly increased in capacity.

IMMERSION HEATERS.

A new immersion heater has been produced in which the element is made on the lines of the hot plate just referred to, *i.e.*, the heating coil is embedded in refractory material contained in grooves in a cast iron former; the element in the present

case is then cast in solid aluminium. The advantages of this type of heater are that it is extremely robust, that access of air to the wire is practically eliminated, and that owing to the fact that the wire is completely embedded, the temperature is very much lower than would be in the case in an open wire heater of similar dimensions.

ELECTRICAL ACCESSORIES.

Though possibly less spectacular than some of the advances made in such subjects as high tension engineering, illumination and telephony, the improvements made in the design and production of electrical accessories form no small contribution to the year's progress.

Fig. 50.—150 kW "Magnet" furnace of the multi-car type annealing aluminium sheets in the works of The Aluminium Corporation, Ltd., Dolgarrog. Internal dimensions of furnace 24ft. long by 7ft. 5in. wide.

A rapid make rapid break lighting switch styled the "Landor" has been introduced during the year. Its action presents many novel features while the insulation is practically perfect. The range of "Bakelite" and "Roanoid" covers available for the switch offer a wide selection of attractive colours.

A further development of this type of switch is the "Silent Landor" switch in which noise in operation, the inherent fault of all quick make and break switches, is completely eliminated by the introduction of rubber buffers of a special quality. On operating the switch the underslung movement closes silently against the rubber buffers. This form of switch is particularly suitable for hospitals, ships cabins, and the like, where quietude is desirable.

An innovation in the link action type of switch permits the conductors to be brought through the base of the switch for connecting to front wiring terminals after the switch is mounted in position. This is known as the G.E.C. "Deeble" switch, one of the chief advantages of which is that inspection of the wiring and connections can be inspected at any time by simply removing the cover.

Improvements have been made to wall sockets and plugs due to the close contact between plug pins and sockets tubes which is now attainable. This ensures a minimum millivolt drop, and tolerances well within the limits provided for by British Standards Specification No. 372.

Attention has been directed towards prevention of accidents, by providing insulated lampholders for industrial purposes with protecting shields to prevent accidental contact with lamp caps whilst inserting or removing lamps from the holder. Lampholders made completely of porcelain for B.C., E.S. or Goliath Screw, and embodying this protective device are now available.

High tension batteries have had new features incorporated. One of these relates to the lengthening of life of a battery. When a battery is old, the zinc of a unit may become punctured and allow electrolyte to escape and creep, thereby causing a number of units to become short circuited. To prevent this, each separate unit is wrapped in a specially waxed paper, which improves the insulation of the battery, and effectively prevents the leakage of the electrolyte.

MOULDED INSULATION.

The use of bakelite has again been considerably extended. For instance, it forms the case of a standard range of bells which are available at a price which competes successfully with low priced wood-cased bells of foreign manufacture. The range of these bells is extended to patterns suitable for working off 100/110 volts and 200/250 volts either direct or alternating current.

One of the most notable developments in the use of bakelite, is the manufacture of the hand type of telephone receiver and microphone. The Gecophone Handcom set is moulded with the earpiece, microphone and holder all in one piece, the connecting wires being moulded in position.

Another branch of the industry in which bakelite has been increasingly used is that of wireless; a new application is for loud speaker cabinets, the mouldings required being the largest produced and involving the installation of new presses having a capacity of 600 tons. Cases for torches are now being made of bakelite which provides a high insulation resistance and thus eliminates the risk of short circuit and leakage associated with metal cased torches.

Electric Propulsion and Equipment of the Q.T.E.V. "Monarch of Bermuda."

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Electric propulsion has won for itself a commanding position in modern marine engineering. Its potentiality for effecting high economies and its great flexibility of control are factors which are rapidy revolutionizing marine standards.

In the accompanying article the authors describe the turbo-electric propulsion and auxiliary electrical equipment of the Q.T.E.V. "Monarch of Bermuda." It is of interest to record that The General Electric Co. Ltd. are supplying an identical electric propulsion equipment for a sister ship which is now being built.

THE Q.T.E.V. "Monarch of Bermuda" is a quadruple screw turbo-electric luxury liner built by Vickers-Armstrongs Ltd., to the order of Furness, Withy & Co., Ltd., and designed under the supervision of William Esplen, Son and Swainston, Ltd., for the carriage of passengers, mails and general and refrigerated cargoes between New York and the islands of Bermuda. This service, which is controlled by the Bermuda and West Indies Steamship Company (an associated concern of Furness, Withy & Co., Ltd.), is probably the most luxurious in the world, the wealthy patrons demanding an extremely high standard of comfort and entertainment. It will be remembered that about four years ago the motor liner "Bermuda" was built and commissioned for the same service. Unfortunately, she was burnt out at Belfast while undergoing repairs at her builder's yard following a disastrous fire which occurred in Hamilton, Bermuda. The completion of the "Monarch of Bermuda" was therefore hastened and, although only launched in March, 1931, she was completed and started on her maiden voyage to New York in November of the same year.

It will be seen from the frontispiece of this issue of the *G.E.C. Journal* and from fig. 1, that the new vessel has exceptionally pleasing lines. The grey painted hull surmounting the green band on the water line, the cruiser stern and widely flared bows combine with the lofty superstructure and the three black and red funnels to make a really handsome ship.

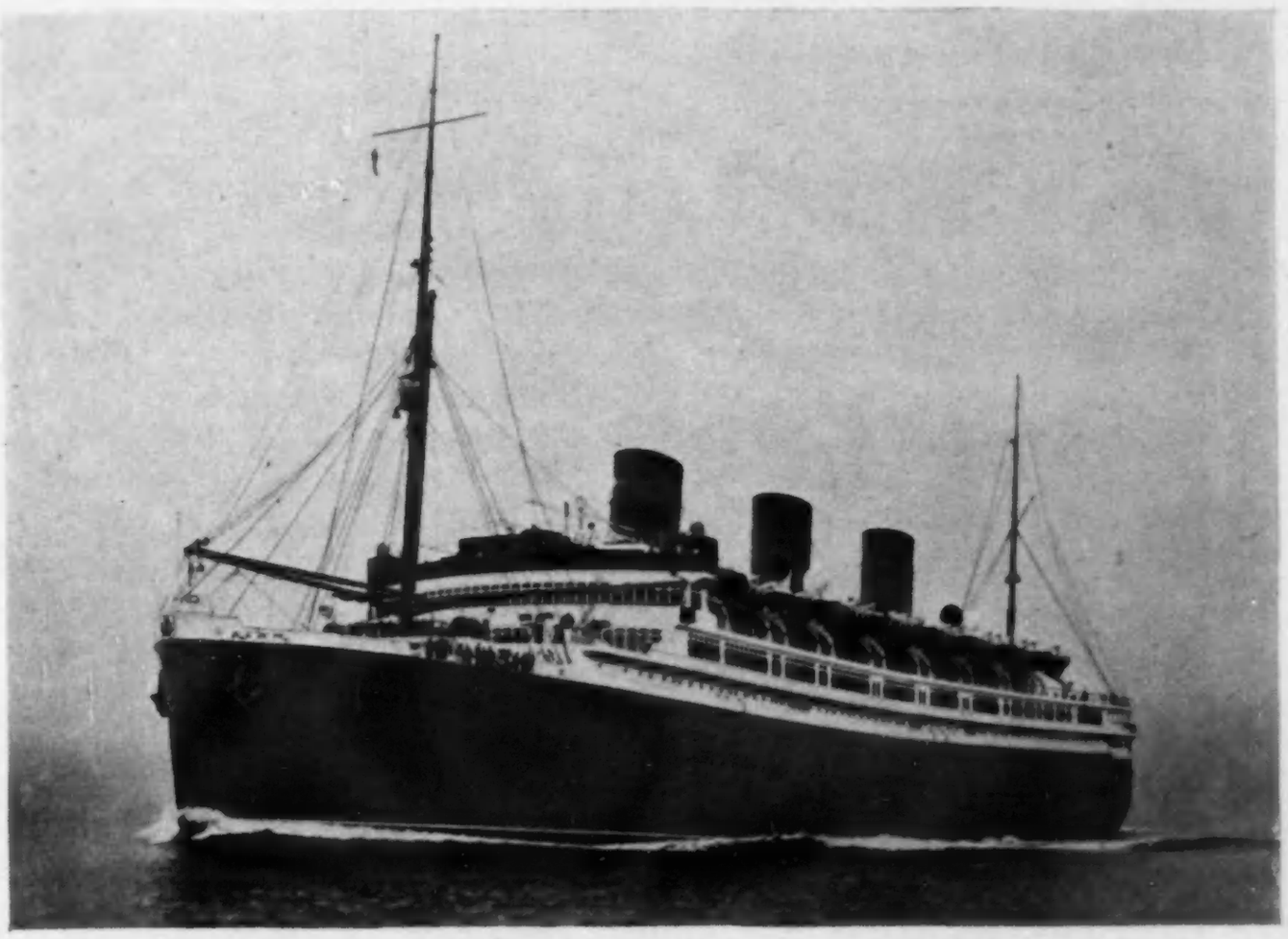

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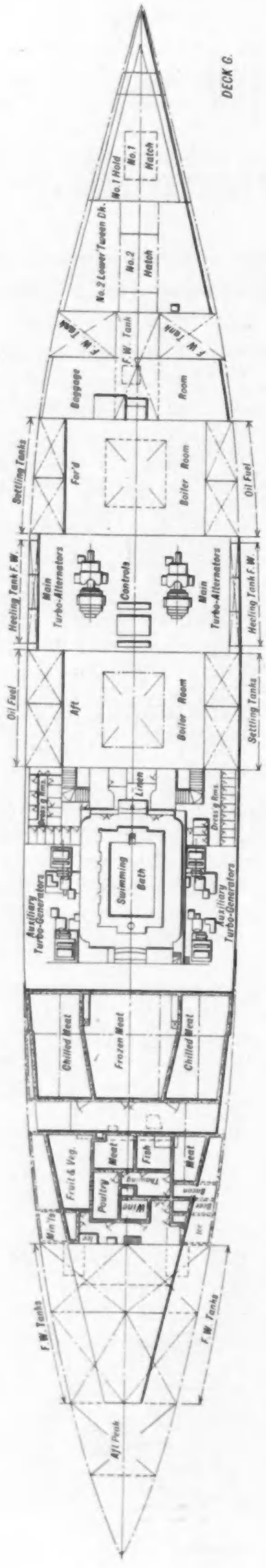
Fig. 1.—The Q.T.E.V. "Monarch of Bermuda."



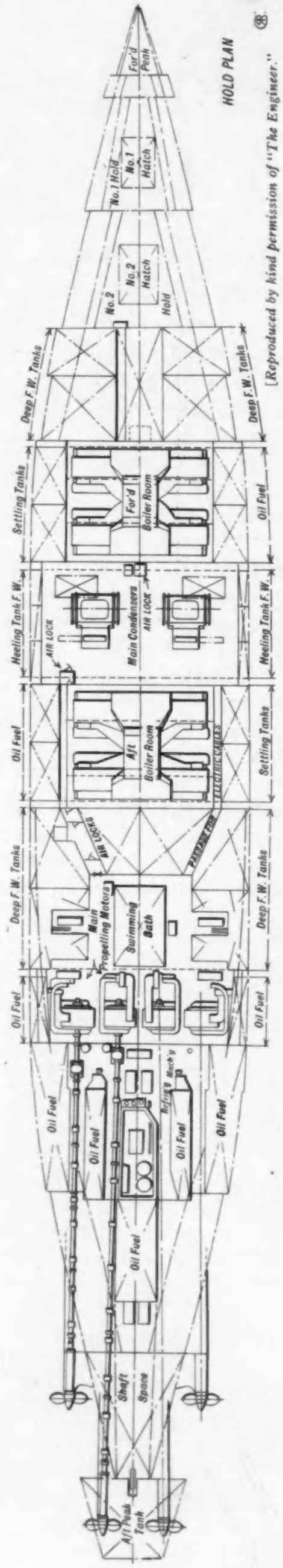


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Fig. 2.—Sectional plans through Deck G and Hold of the Q.T.E.V. "Monarch of Bermuda."

In addition to the four complete steel decks running the entire length of the ship there are two almost complete decks in the superstructure, and a number of steel decks in the holds at the forward and after ends. The hull is divided into several watertight compartments by watertight bulkheads equipped with hydro-electrically operated doors controlled from the bridge. This, together with the double bottom and double skin carried up to the water line, ensure maximum safety at sea.

Particulars of the passenger accommodation and the principal dimensions of the hull are given below.

First-class passengers	831
Second-class passengers	31
Officers and crew	approx. 455
Total number of persons carried ..	„ 1317
Length overall	579ft. 6ins.
Breadth moulded	76ft. 6ins.
Breadth extreme	83ft. 6ins.
Loaded draught	26ft. 3ins.
Gross tonnage	approx. 22,500 tons
Trial speed	21 knots

ELECTRICAL EQUIPMENT.

The electrical equipment of the "Monarch of Bermuda" represents the very latest practice in modern marine electrical engineering. Electricity is used on the most extensive scale possible throughout the entire ship, from the actual propulsion and steering of the vessel, to the lighting, heating and ventilation of all the sumptuous public rooms, cabins and other spaces, the refrigeration and cooking of food, the handling of cargo, the signalling and indicating devices, communication, the driving of the laundry machinery, gymnasium equipment and printing presses and many other services. In fact it is probably true that in no other ship in the world is electricity used on a more comprehensive scale.

It is one of the remarkable features of the "Monarch of Bermuda" that, with minor exceptions, the whole of the electrical plant and apparatus installed has been manufactured by one British firm—The General Electric Co., Ltd., of England. Some idea of the magnitude of this undertaking may be conveyed by the following list of the most important items of electrical equipment supplied.

Main Propulsion Equipment.

2—7,500 kW G.E.C.–Fraser & Chalmers turbo-alternators, generating current for the propulsion motors.

4—4,750 h.p. "Witton" A.C. propulsion motors, each driving a separate propeller.

3,000-volt propulsion cubicles housing control switchgear.

Auxiliary Generating Plant.

4—750 kW G.E.C.–Fraser & Chalmers geared D.C. turbo sets generating current for auxiliary purposes.

20—Panel main D.C. switchboard, 56ft. long.

Auxiliary Motor Drives.

270—"Witton" marine type motors with a total capacity of over 3,000 horse power, driving all the ship's auxiliaries such as pumps, windlass, winches, capstans, ventilating fans, steering gear, laundry machinery, etc. In many cases these motors are controlled by push buttons on the patented G.E.C. "plural starter" system.

Passenger and Goods Lifts.

13—"Express" electric passenger and cargo lifts.

Illumination.

20,000 Osram lamps.

5,000 lighting fittings of various types.

This very comprehensive equipment is installed for the lighting of all the public rooms, decks, cabins, engine rooms, etc. A stage lighting equipment is also installed, while floodlights are provided for illuminating the upper structure of the vessel at night.

Galley Equipment.

The galley is the most completely equipped electric installations of its kind afloat. It includes :—

Electric island ranges.
Electric hot cupboards.
Electric fish fryer.
Electric salamanders.
Electric hot plates and carving tables.
Electric water boilers.
Electric urns.
Electric grillers.
etc., etc.

Communication, Signalling and Indicating Devices.

150—Telephones and telephone exchange which can be connected to any type of exchange on shore.

250—Electric signs and indicators.

2,250—Bell pushes with bells, indicators, etc.

A complete electric fire alarm system is also installed.

Heating and Ventilating, etc.

400—Electric convector heaters for cabins, etc.

100—Electrically heated towel rails.

15—Electric convector radiators for public rooms.

650—Electric fans for cabins.

125—Electric motors for ventilating units.

Wires and Cables.

410 miles of conductor are used for connecting up the apparatus. This was supplied by the Pirelli-General Cable Works Ltd. (an associated Company of the G.E.C.), the whole of the wiring being undertaken by the Sunderland Forge and Engineering Co. It should be mentioned in passing that the contract for the wiring of the vessel involved the connecting up of approximately half-a-million separate conductor ends and the whole of the work was carried out in an exceptionally short time. For the protection of the various lighting circuits, etc., 5,000 Home Office cartridge type fuse units have been supplied.

* * * *

In the following description it is proposed to deal with each of the above sections in turn, although limitations of space allow of only brief descriptions of all but the propulsion equipment.

MAIN PROPULSION EQUIPMENT.

The "Monarch of Bermuda" has four propellers transmitting approximately 19,000 total shaft horsepower continuously. Each propeller is separately driven by a 4,750 h.p. synchronous motor at a speed of 150 r.p.m. The four motors are supplied with current at 3,000 volts from two 7,500 kW G.E.C.-Fraser & Chalmers turbo-alternators, running at 3,000 r.p.m. It is possible by the provision of a simple system of switching, which will be described later, to connect each of the propulsion motors to either of the two turbo-alternators, although in normal circumstances the ship functions in a manner similar to a twin screw vessel, the two port propulsion motors operating in unison either ahead or astern from the port alternator, and the two starboard motors operating in unison ahead or astern from the starboard alternator.

Both turbo-alternators, one of which is shown in fig. 4, are situated in the forward engine room, between the two boiler rooms, each set consisting of a Fraser & Chalmers high pressure, multi-stage impulse turbine coupled to a "Witton" alternator. The turbines are designed to operate with steam at 350 lbs. per sq. inch pressure and 650°F total temperature, 28 ins. vacuum, and are specially arranged for low head room, having a broad exhaust casing which takes full advantage of the vacuum and provides adequate attachment for the condenser which is bolted on the turbine exhaust flange and supported on springs.

The turbine shaft is rigid and has its first critical speed well above the maximum running speed, while the shaft packings are of Fraser & Chalmers patented labyrinth design. The fitting consists of a forged steel box in the casing of the turbine provided with a number of fine fins projecting towards a similar set of fins turned on a separate sleeve on the rotor. Both sets of fins have different pitches so that the majority of the fins in the box and sleeve are not situated directly opposite each other. This construction allows a large number of fins to be used with fine clearances without incurring any danger of wear, and in the event of fins making contact, the arrangement is such that they do not touch the shaft, but engage with fins on the wheel hubs or on separate sleeves on the shaft. The heat thus generated by rubbing cannot warp the shaft.

The turbine wheels are pressed on the shaft with the appropriate hydraulic pressure to ensure that they do not work slack at overspeed, while each wheel is mounted on a separate seat and drives on a separate key. The moving blades, which are machined from solid bars of stainless steel, are of heavy section and are individually riveted to the wheel rims. For the first stage of the turbine the nozzles have plates of Hecla A.T.V. cast into the nozzle blocks which are a special mixture of cast iron.

The diaphragms are divided at the horizontal joint, the top halves being held by screws in the top half of the turbine casing so that they can be lifted with the casing clear of the rotor. The guide vanes, which are cast into the diaphragms, are of stainless iron of the correct profile, while the steam nozzles formed by the plates are fescolized. At the exhaust end of the turbine, where the steam becomes wet, the diaphragms are given a special profile opposite the blade tips to trap the moisture which is thrown off by centrifugal action, and to drain it away from the steam passages direct to the condenser.

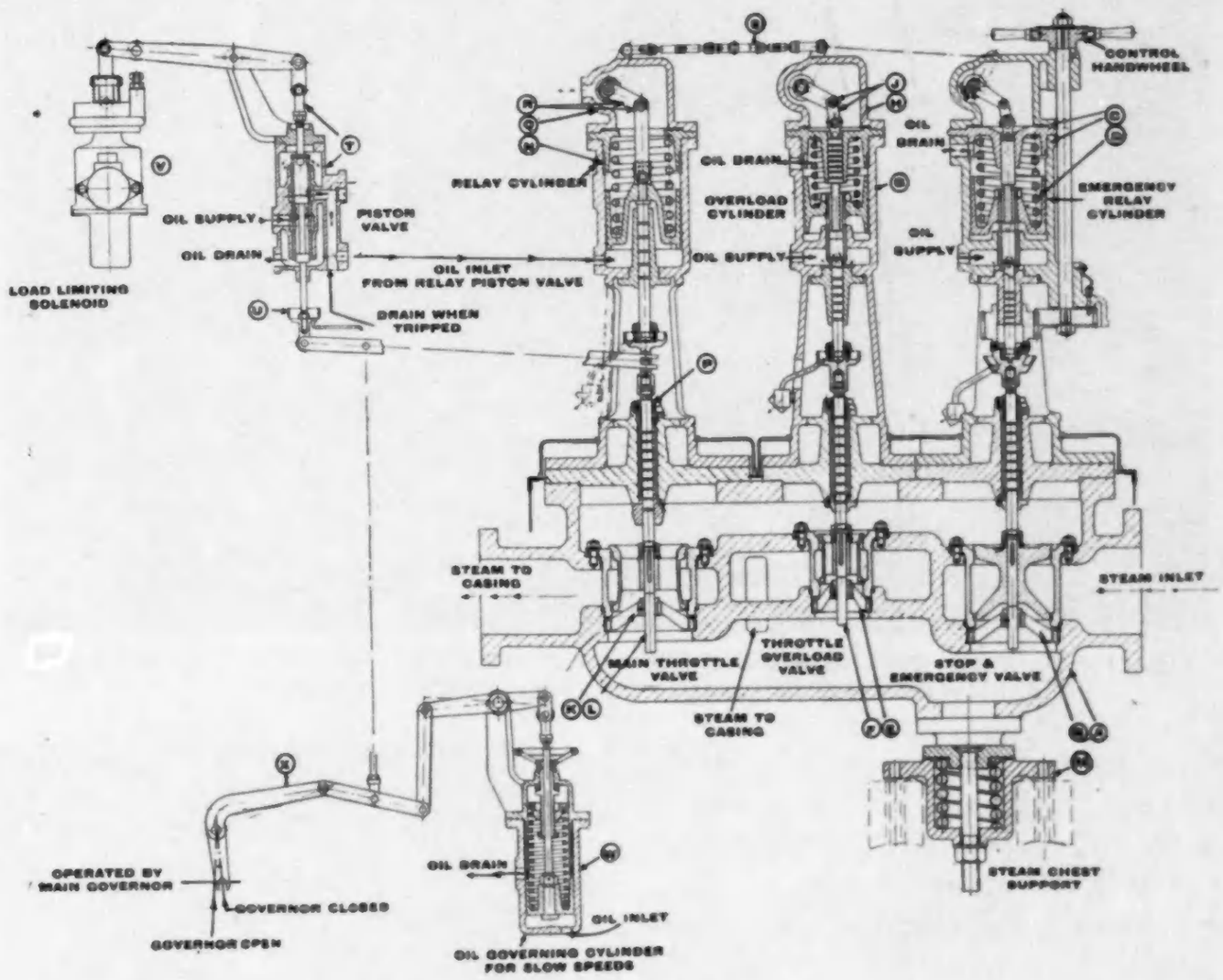
A Michell thrust bearing of Fraser & Chalmers design is situated at the forward end and locates the turbine rotor. The working faces of the bearing provide ample surface to carry all thrust due to steam pressure and the pitching of the ship, and the design is such that an adequate circulation of oil over the bearing surfaces is assured.

A worm gear, which is fitted in the forward bearing pedestal of the turbine, drives a horizontal spring-loaded speed limit centrifugal governor, while a second worm at the outer side of the thrust bearing drives two oil pumps, one for the lubrication and relay system and the other for the main control device. An emergency governor is also fitted at the extreme end of the shaft to trip the emergency gear at 10 to 12 per cent overspeed and is of the eccentric ring spring loaded type, operated direct from the turbine shaft. For ordinary running, the main control gear determines the speed of the turbines; in emergencies, the centrifugal governor will check the speed of the turbine. The emergency governor is a further safety device which, by tripping the emergency gear, reverses the oil connections to the relays, and assists the springs in closing the stop

and throttle valves by applying full oil pressure above the relay pistons and releasing the oil beneath them.

The sectional arrangement of the main steam chest is shown in fig. 3, from which it will be seen that each valve has its own relay cylinder and pilot valve. The first valve, which is known as the "stop and emergency valve" has a hand gear for securing it in the closed position when the oil pressure is off. This stop valve rises and falls with the main and overload valves, but at a slightly faster rate in order

device consists of a spring-loaded diaphragm which is held down by the vacuum so that steam cannot be admitted to the turbine until the condensing plant has been started and a vacuum established. The standard Aspinal oil control gear is connected to the lubricating system to operate the bulk-head self-closing valves on the main steam pipes, and to prevent their being opened until the lubricating oil pressure is established. Provision is made for tripping this gear by hand both in the engine room and from the deck.



REFERENCE TABLE.

A Steam chest.	**J** Spindle guide and levers.	**R** Spindle guide and levers.
B Emergency valve and guide.	**K** Throttle valve, cage and guide.	**S** Connecting rods.
C Relay cylinder and cover for emergency valve.	**L** Throttle valve spindle.	**T** Load limiting gear and piston valve.
D Details of relay cylinder for emergency valve.	**M** Steam chest support.	**U** Oil cup and levers.
E Overload valve, cage and guide.	**N** Relay cylinder and details.	**V** Solenoid.
F Overload valve spindle.	**P** Sleeve for cylinder baseplate.	**W** Oil governing cylinders.
G Overload cylinder and details.	**Q** Cover for relay cylinder.	**X** Governing levers.
H Cover for overload cylinder.		

Fig. 3.—Section through steam chest, relays and governing gear of the 7,500 kW main turbines.

to give the advantage of two stage throttling of the steam, a feature which is particularly valuable at very low speeds, as with the high pressure of the steam used it is essential to have accurate control over very small volumes of steam. The valves and their cages are cut from solid forgings of high tensile steel, while the seats are accurately ported to give the correct load lift characteristics.

In addition to the three governors already mentioned, a further novel safety device is incorporated with the emergency gear to trip the turbine if the vacuum in the condenser fails. The

The lubricating oil for the turbine and alternator is supplied by the worm-driven gear type pump to which reference has already been made. The pump supplies oil at 60 lbs. per sq. inch pressure for the relays, the pressure being reduced to 15 lbs. per sq. inch through a control valve box for the bearings. Both the bearings and relay systems have relief valves to prevent excessive pressure. At low speeds the full oil pressure cannot be obtained from the main pump, and a motor driven rotary pump with a pressure relay is automatically brought into operation. In the event of failure of this pump, there is also a

steam driven centrifugal pump with a double pressure relay, which will start automatically if both the main and motor pumps have failed to produce the proper pressure.

Each turbine is controlled by a large handwheel, which is situated on the main control panel in the centre of the engine room. For each position of the control wheel there is a definite turbine speed so that the engineer has full control over the turbine and can raise the speed from the minimum running speed to full speed by the simple operation of this wheel.

A flexible coupling is employed between the turbine and alternator, and is fitted with internal collars to limit the relative movement of the two rotors when the ship is pitching.

As previously mentioned, each of the alternators is rated at 7,500 kW, 3,000 volts, 3 phase, 50 cycles at 3,000 r.p.m., and is provided with a closed circuit cooling system having tubular type sea-water coolers. Both alternators are continuously rated and the maximum temperature rise, ascertained by the six temperature indicators embedded in the stator and by resistance measurement in the case of the rotor, is substantially within the limits laid down by British Standard Specifications. Mica and micanite insulation are used throughout the construction and in order to maintain the insulation in good condition, free from condensation, during the periods when the alternators are not in use, two 1 kW electric heaters are embodied in the frame of each machine.

Excitation is obtained from the 220-volt ship supply generated by the four auxiliary generators which are referred to later. The excitation is in each case applied through the medium of a special negative booster of 23 kW capacity, fig. 5, which provides over excitation for starting. Three booster sets are installed, one acting as a reserve.

The four propulsion motors, fig. 6, are situated aft in the motor room, the supply from the alternators to each motor being taken through special propulsion type cables.

The design of the Pirelli-General propulsion cables received careful consideration. Two factors had to be borne in mind : firstly, the confined space in which the cables had to be installed, and secondly, the ambient temperature in which they would be called upon to function.

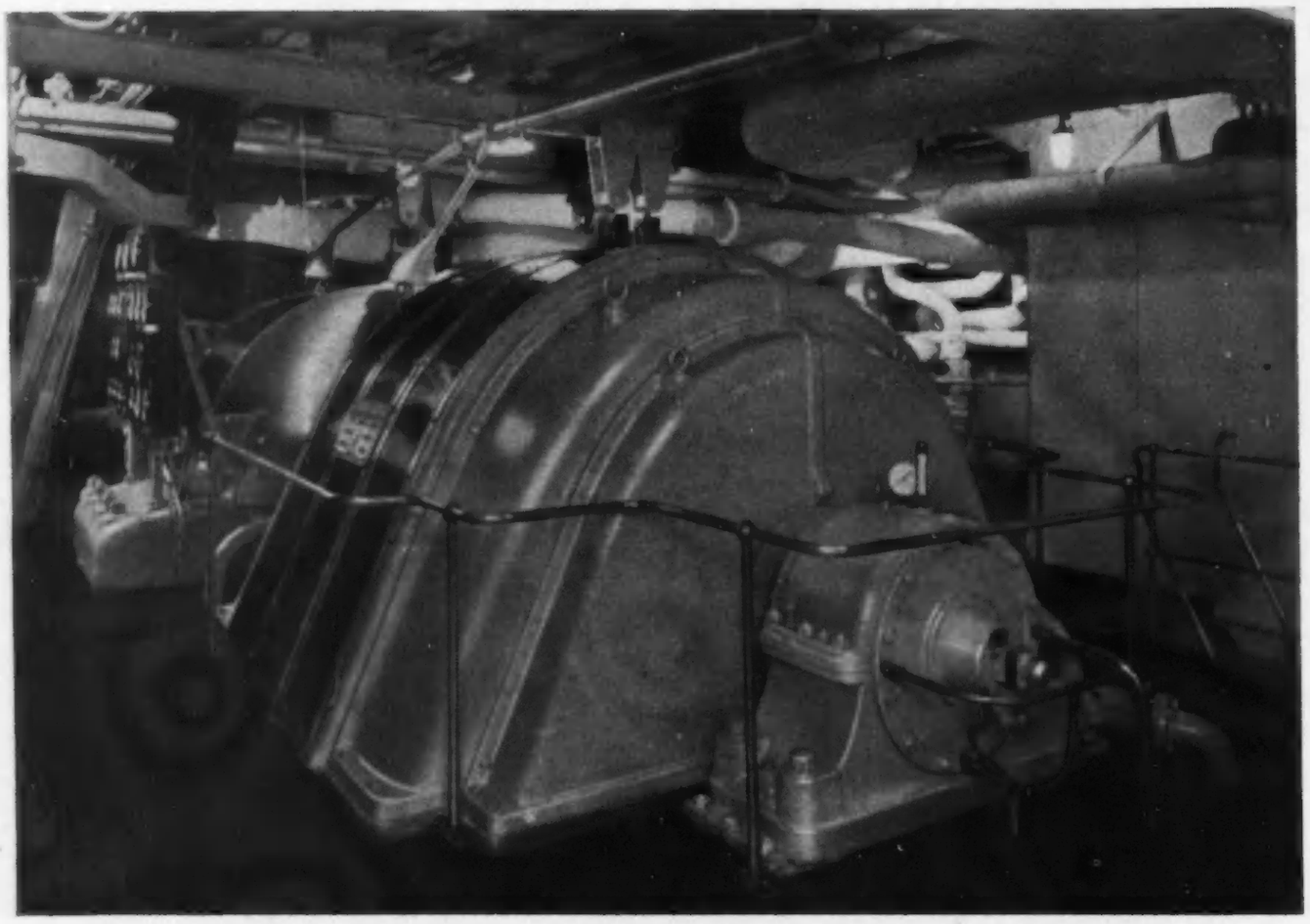


Fig. 4—One of the two 7,500 kW, 3,000 volt, 3 phase, 50 cycle, 3,000 r.p.m. turbo-alternators supplying power to the propulsion motors.

Fig. 5.—Two 23 kW negative booster sets installed to provide over-excitation of the alternators during starting.

The question of vibration had also to be considered in view of the possible crystallization of the lead sheath, and it was at first suggested that instead of lead sheaths, hard rubber sheaths and varnished cambric insulation should be employed.

All the above facts being taken into consideration, it was finally decided that instead of using one group of very large conductor single-core cables per motor, a number of three-core cables in parallel should be employed which would be easier to handle in

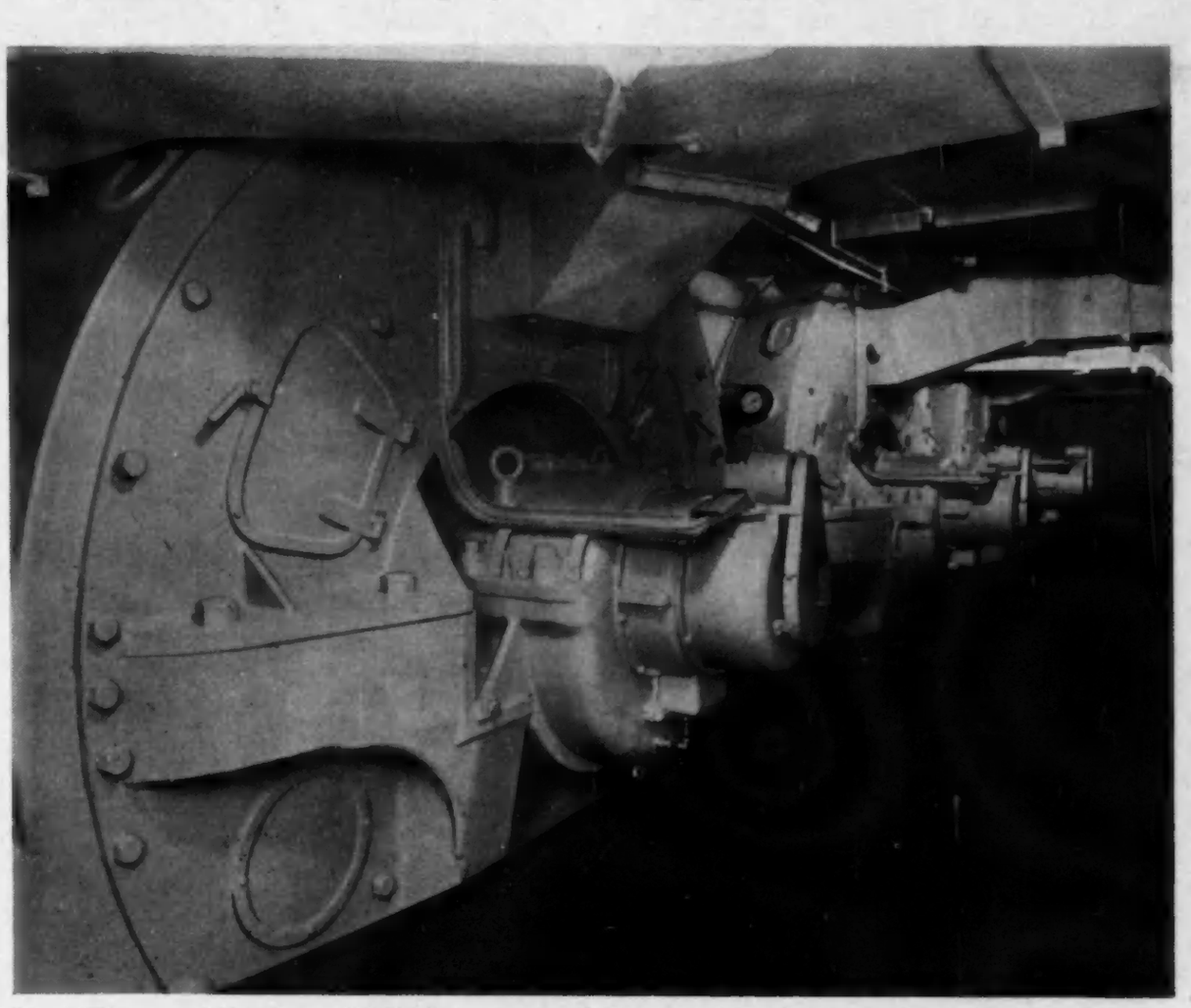


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Fig. 6.—Three of the four 4,750 h.p. propulsion motors installed aft in the motor room. Each is coupled to a separate propeller shaft which it drives at 150 r.p.m.

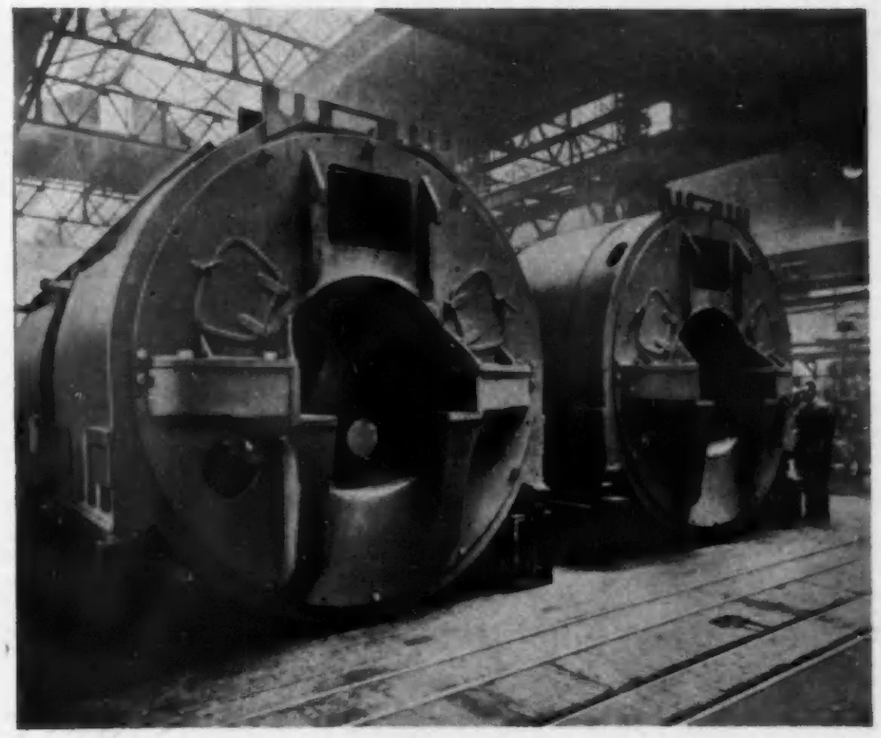

Fig. 7.—View of the fabricated stators and end-shields in course of erection.

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Varnished cambric insulation has the great advantage of being non-hygroscopic and, therefore, would not deteriorate should any damage be caused to the sheath. Furthermore, it requires no special sealing ends and could therefore be accommodated more easily in the restricted spaces. Owing, however, to the proximity of the cables to the oil bunkers on certain sections of the run, the use of hard rubber sheaths was precluded.

position than the big single-core type. The actual cable installed consists of three tinned copper conductors of .45 sq. in. cross section, insulated with varnished cambric for the full voltage of the supply, each core being braided and each phase indicated by colour, the cores wormed circular, lead sheathed and braided overall and finally impregnated with fireproof compound.

These cables are installed in groups of three, two groups on the starboard side and two on the port side. In passing through watertight bulk heads, non-ferrous metal packing glands are employed to ensure proper watertight protection between one compartment and the other. The ends of the cables themselves are taken to terminal boxes, mounted on the motors and in the control switch cubicles, the fixing formation being two groups of three placed one in front of the other and supported by means of hard wood cleats fixed to the ship's structure.

Each propulsion motor is of the totally enclosed 3-phase, salient pole synchronous type, provided with heavy damping windings in the pole faces to develop the high torque required during the reversing of the ship. Each motor develops 4,750 h.p. at 150 r.p.m. and is direct coupled to a propeller shaft. In spite of the high power which they develop, the motors are exceptionally light, a feature which is

chiefly due to the use of completely fabricated stator and end shields, fig. 7. The shaft of each motor is of massive construction and is supported at each end by bearings mounted on the end shields. Pumps incorporated in the bearings provide flow lubrication, while oil rings are also fitted in case of emergency and are so designed that they can function at the maximum possible list of the ship in all directions. A separate completely enclosed system of ventilation is installed for each motor and consists of a motor-driven fan and tubular sea-water cooler, together with the necessary trunking.

independent set of busbars from which it may be isolated by means of the switches IA1 and IA2. Each motor is also provided with a two-way isolating switch enabling it to be connected at will to either alternator. By this means a large number of running combinations are available to deal with various conditions of service and a high degree of reliability is ensured in case of emergency. It will be seen that each motor is provided with two double pole contactors to enable the machines to run ahead or astern.

In starting, the propulsion machines function as induction motors, the sequence of starting being as follows. The steam turbines are run up to about

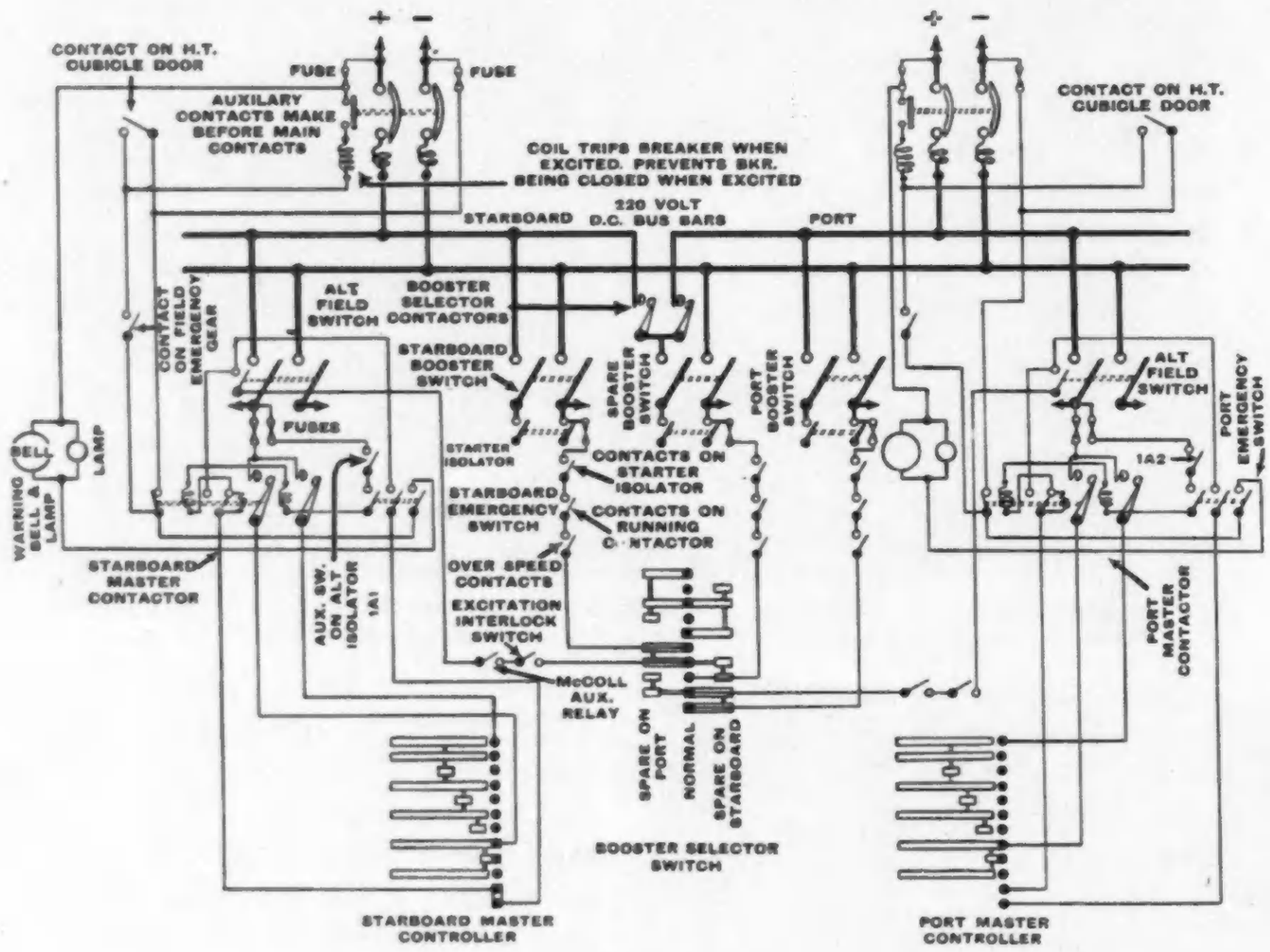


Fig. 8.—Excitation circuits.

The insulation throughout is of the highest class to withstand possible corrosion by sea air and the moist heat of tropical climates. In particular, the rotor is insulated to withstand the high induced voltages occurring during the reversing of the ship. As in the case of the alternators, electric heaters are inserted to maintain the windings at an even temperature when the ship is in port.

By the ingenious form of construction employed, it is possible to inspect each of the rotors on site by removing the end shields and racking the stator clear of the rotor.

SYSTEM OF CONTROL.

The control scheme will be more clearly appreciated by referring to the diagram, fig. 9, which shows in single line form the switching arrangements of the two alternators and four motors. It will be seen that each alternator is connected to an

$\frac{1}{6}$th speed without any excitation on the alternator or motor fields. The direction contactors are then closed, for either ahead or astern running as desired, and the speed of the alternators is increased to about $\frac{1}{5}$th full speed in order to secure reasonable starting torques on the propeller motors.

At $\frac{1}{5}$th speed, the alternator fields are over-excited and the motors begin to revolve, operating for the time being as induction motors, until they reach a maximum speed with the alternators at $\frac{1}{5}$th speed.

The motor fields are then excited and the motors pull into synchronism, continuing to run at $\frac{1}{5}$th speed as synchronous motors. The alternator fields are then reduced to normal excitation, and the speed of the alternator can be varied to any desired value between about $\frac{1}{6}$th speed and full speed.

In stopping, the speed of the turbine is reduced to about $\frac{1}{6}$th speed, and all excitation cut off.

Reversal is accomplished by first carrying out the same operations as for stopping, namely, reducing speed to about $\frac{1}{8}$th, opening the excitation circuits, and changing over the direction contactors. The starting operations are then repeated.

Various methods of running are available as follows :—

(1) NORMAL. Two port motors fed by the port alternator, and two starboard motors fed by the starboard alternator—full speed of vessel obtained.

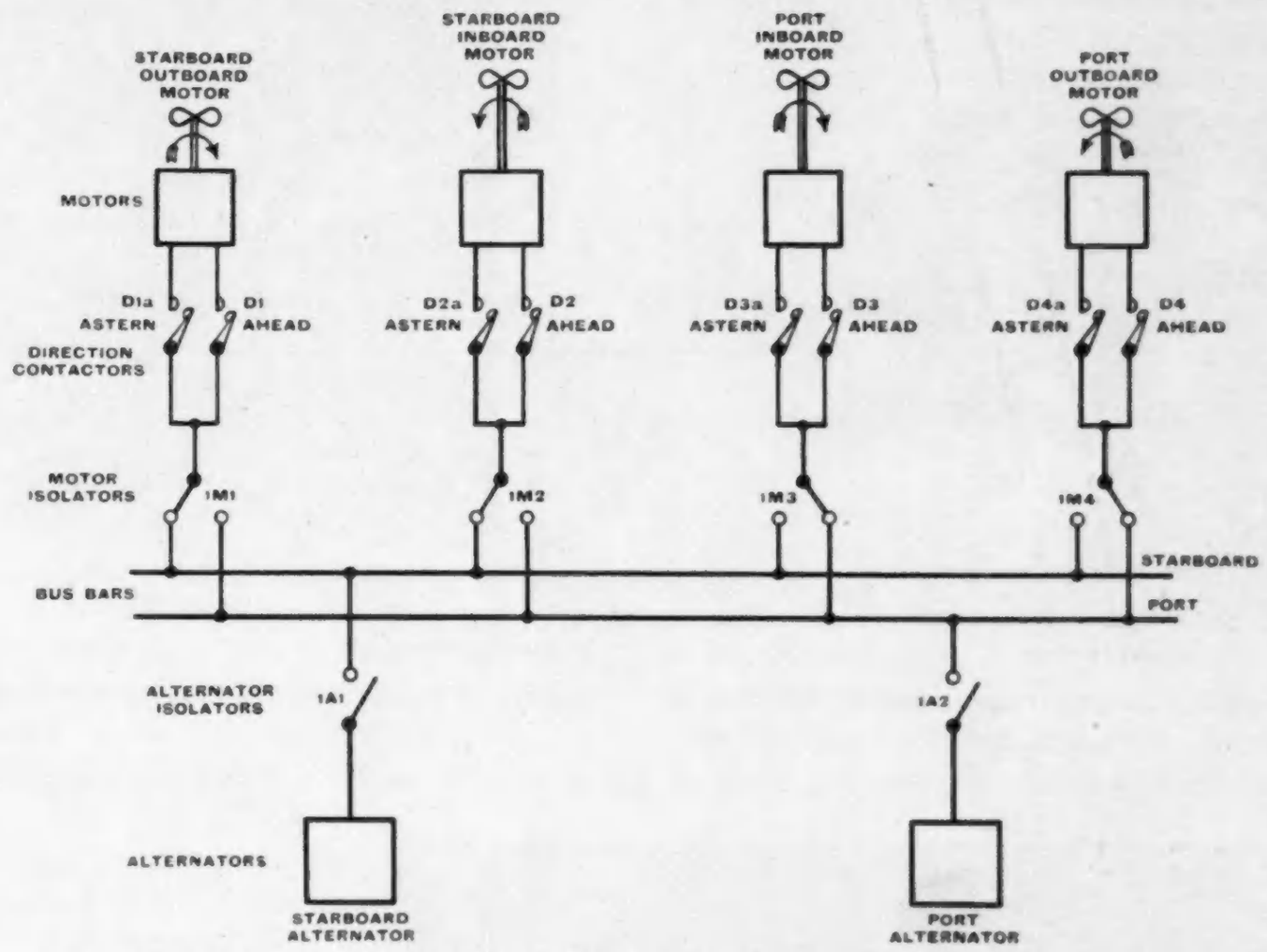


Fig. 9.—Single line diagram of high tension circuits of propulsion equipment.

(2) One port motor fed by the port alternator and one starboard motor fed by the starboard alternator—maximum speed of ship possible about 70 per cent.

(3) Four motors fed by either alternator only—maximum speed of ship about 70 per cent.

(4) Two outboard motors fed by one alternator and two inboard motors fed by other alternator—full speed of vessel obtained.

All electrical switching operations are carried out at low voltage, thus avoiding the necessity of rupturing heavy currents at the reversing contactors. The latter do not operate until all excitation has been cut off and are thus not called upon to break heavy currents. They are capable, however, of rupturing considerably more than full load current.

With one or more machines out of commission it is necessary to limit the propeller revolutions in order to avoid overloading the plant in commission. For this purpose there are provided four solenoids which act on the turbine governor gear to prevent the speed and load of the turbine being increased beyond a safe limit. These solenoids are automatically energised to give a limited power condition whenever any of the isolating switches are operated.

If the alternators are each feeding only one motor, similar automatic means are provided to prevent the alternators from supplying more than the normal load of one motor at approximately 70 per cent speed.

In the unlikely event of an operating coil failing in any part of the main control equipment, means are provided whereby the entire control sequence may be carried out mechanically without in any way sacrificing the protective features which are obtained in electrical operation. In normal circumstances, however, this alternative equipment is inoperative.

In designing the propulsion control equipment care has been taken not only to ensure that an alternative means of operation is available but also to provide ample standby plant and to limit as far as is possible the damage which might result in the unlikely event of an electrical breakdown. The main propulsion machines are protected against earths and phase faults by the well-known McColl circulating current system but using relays designed for marine requirements. In place of the usual beam relay, which would be liable to interference from the rolling or pitching of the boat, a special biassed disc type of instrument is employed which has given remarkably good results, its sensitivity and

stability being fully equal to that of the more usual type.

As the voltage of the main propulsion system is sufficiently high to be dangerous to life, special precautions have been taken to prevent access being gained to the high tension apparatus while the plant is alive. Referring to figs. 11 and 14, it will be seen that the control apparatus is housed in three separate but adjacent steel cubicles, the first of which forms the actual control panel. These cubicles are installed in the centre of the main engine room, the operator having a full view of the ship's telegraphs. The two larger control wheels in the centre of the control panel are used for the starting sequence, while the two outer smaller wheels actuate the mechanical emergency mechanism for the field contacts. Above and outside the main control wheels may be seen the two direction switches each of which, in normal operation, controls the direction of rotation of two propellers, while in a corresponding position on the inside of the main control wheels are the two emergency switches which effect the instant removal of all excitation from the corresponding half of the propulsion equipment. As the main control wheels have a travel of two complete revolutions, a large indicator dial is mounted above each wheel so that the speed setting of the main control wheel may be seen at a glance by the operator.

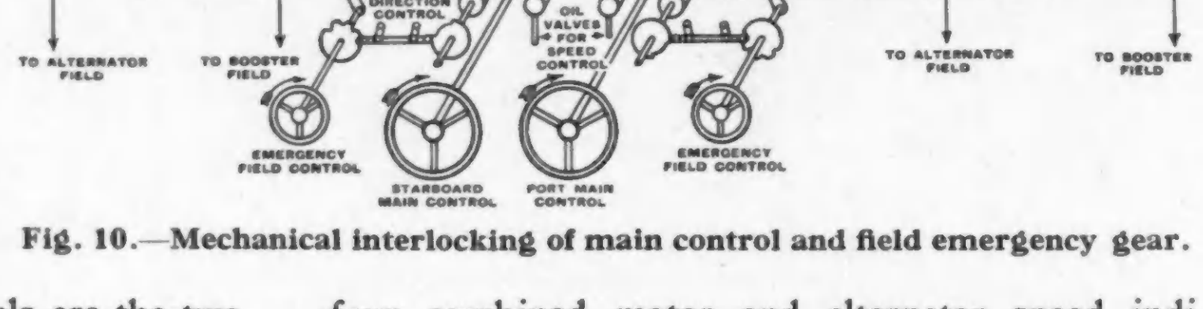


Fig. 10.—Mechanical interlocking of main control and field emergency gear.

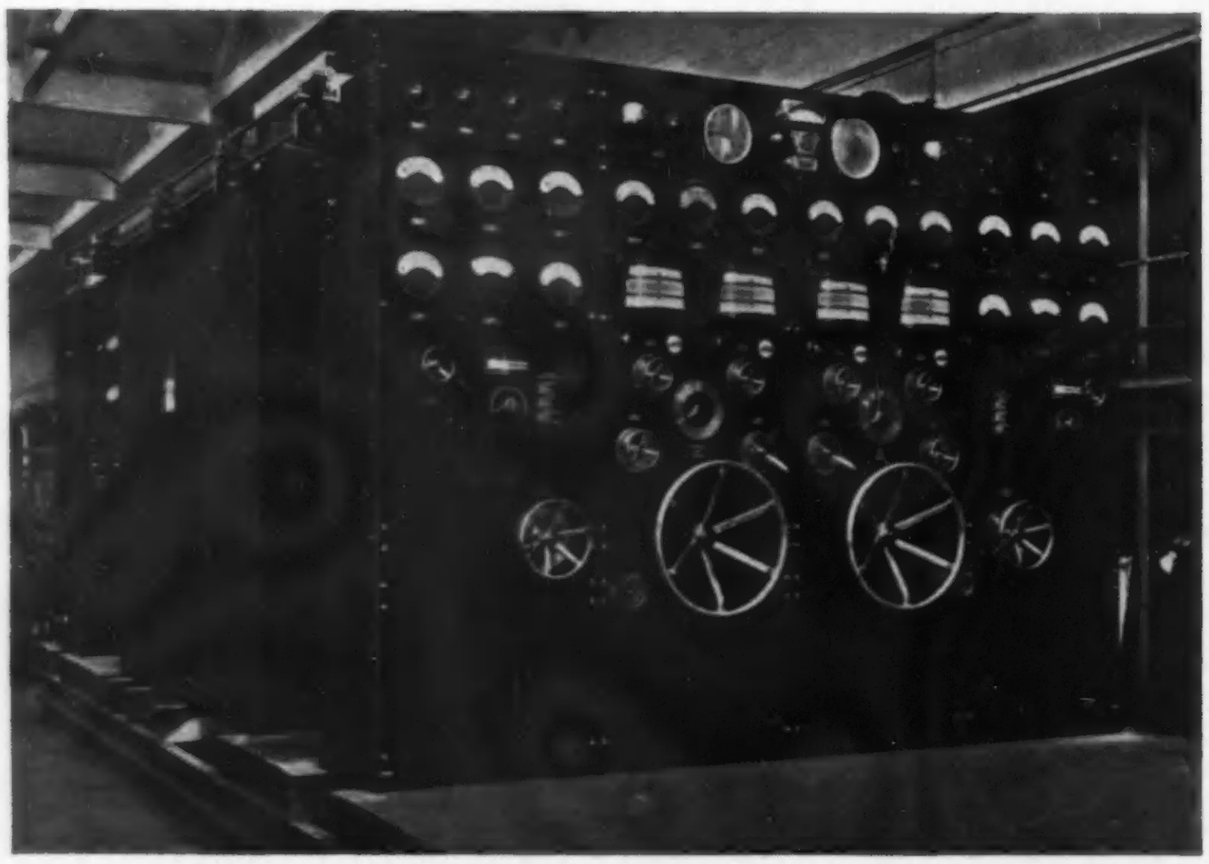


Fig. 11.—High tension control cubicles erected in Witton Engineering Works.

A propulsion motor may be taken out of service by operating the appropriate contactor switch situated just above the indicating dial, while above the contactor switches are the ahead and astern lamps which show the direction of rotation of the main motors. The front of this cubicle also carries four combined motor and alternator speed indicators, the necessary D.C. instruments for the field circuits, wattmeters for each motor, and A.C. ammeters and voltmeters, while alarm bells and lamps for each alternator are provided to inform the engineer in case of an excitation failure.

There are also provided green indicating lamps to show the engineer which of the booster and ventilating fans are running, and temperature indicators for the motors and alternators. The booster field rheostats enable the alternator excitation to be increased if necessary during rough weather. Special stability indicators are provided to indicate the desirability or otherwise of increasing excitation in special circumstances.

The single-way alternator isolators are shown in fig. 13. These isolators together with the direction contactors, fig. 12, are housed in the high tension cubicle, fig. 14. The four hand wheels of the upper row and the two outer hand wheels of the lower row respectively operate the motor and alternator isolators, while the two large hand wheels operate the direction contactors mechanically in the event of failure of the electrical circuits. In order that the operator may know in emergency conditions which direction

of rotation is required, signal lamps for each side of the ship are provided at the top side of the cubicle.

The third cubicle, contains all the direct current switchgear associated with the switching operations of the propulsion equipment, such as machine field contactors, together with the discharge resistances, field isolating switches, temperature alarms and protective relays.

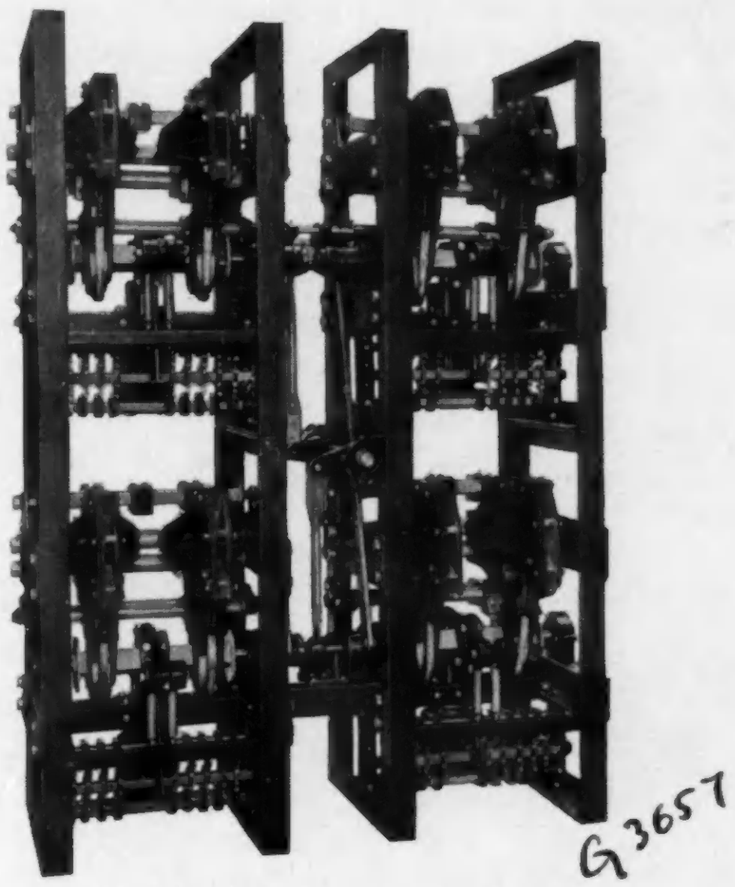


Fig. 12.—Direction contactors.

AUXILIARY GENERATING PLANT AND CONTROL GEAR.

The auxiliary engine room houses four 750 kW G.E.C.-Fraser & Chalmers geared turbo-generators, figs. 15 and 16, the turbines running at 6,000 r.p.m. and driving the generators through gearing at 750 r.p.m. The turbines are of the high pressure multi-stage type, operating under the same steam conditions as the main turbines previously described.

Each turbine is provided with a constant speed governor, emergency governor and vacuum tripping device. These are similar to those of the main sets except that a spring loaded oil piston is connected to the relay system. When the emergency trip operates, this piston loses its oil pressure and operates a switch which throws out the main circuit breaker, and thus prevents the machine being motored.

Lubricating oil for the turbine, gears and generators, and for the relays is supplied by a rotary gear type pump driven by bevel gears from the governor spindle. A hand pump is also provided on the oil tank to flood the bearings on starting up.

A sectional arrangement of the steam chest and emergency valve is shown in fig. 17, which shows the construction of the valves and their cages and the tripping gear for the emergency valve. On starting up, the spring in the relay cylinder holds the valves shut, and starting gear is provided by means of which the valves can be lifted. When the machine starts, oil pressure is established which lifts the throttle valve further, and at the same time automatically releases the starting gear. As soon as the machine reaches normal running speed the governor operates the pilot and brings the throttle valves into the governing position. Hand gear is provided on the governor casing for adjusting the running speed for paralleling the machines.

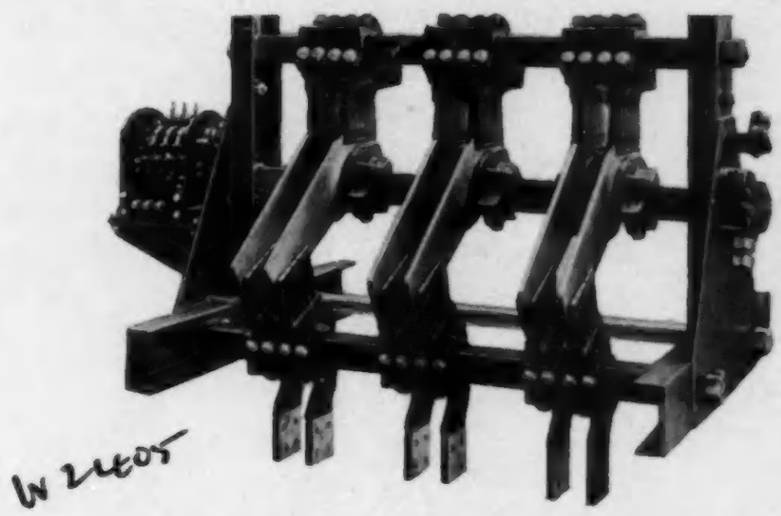


Fig. 13.—Single-way alternator isolators.

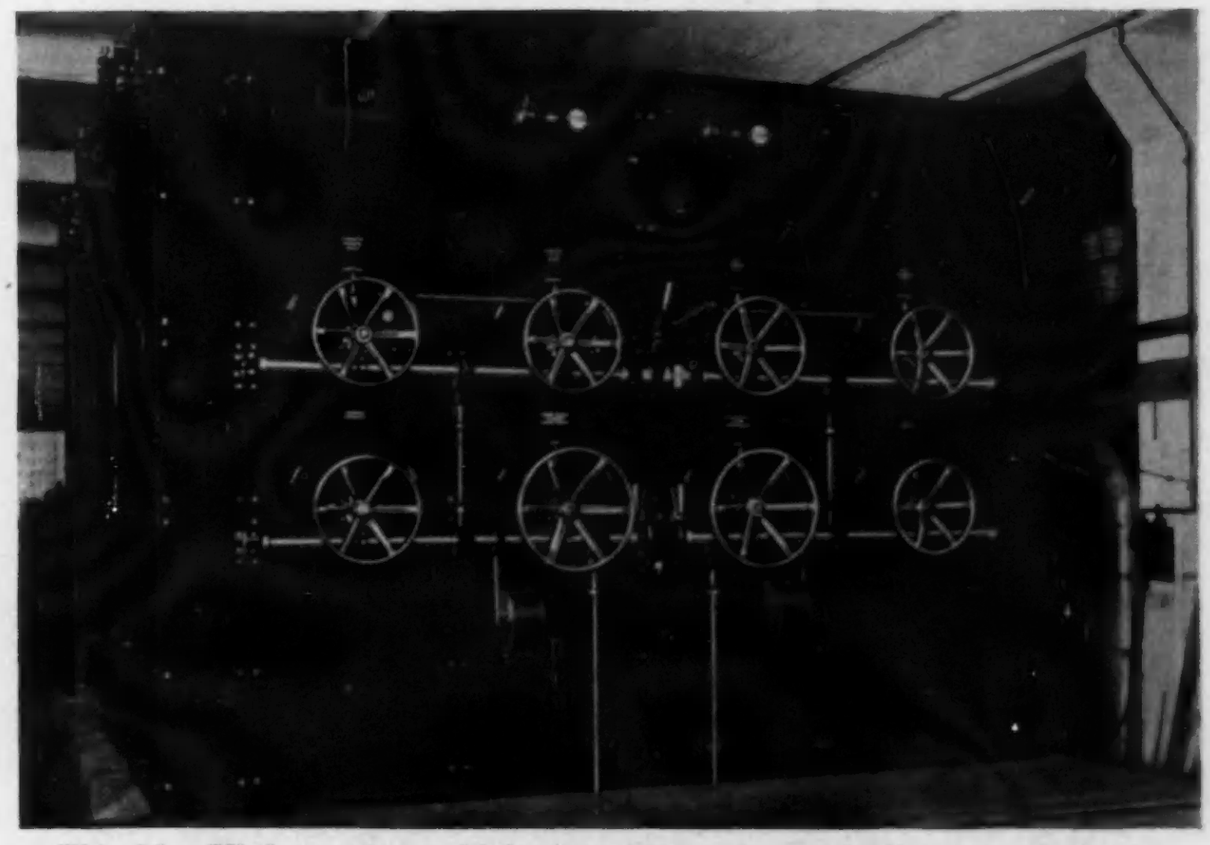


Fig. 14.—High tension cubicle, housing motor and alternator isolators and direction contactors.

Each of the four generators, fig. 16, is of the "Witton" open compound wound, marine type, generating direct current at 220 volts. All four machines are identical in construction and are provided with special insulation and finish for marine engine room and tropical conditions.

The output of each generator is taken direct to the four of the five centre panels of the main D.C. switchboard, fig. 13, which is also situated in the auxiliary engine room. The switchboard is 56 ft. long and comprises 20 panels controlling various feeder circuits for the following services.

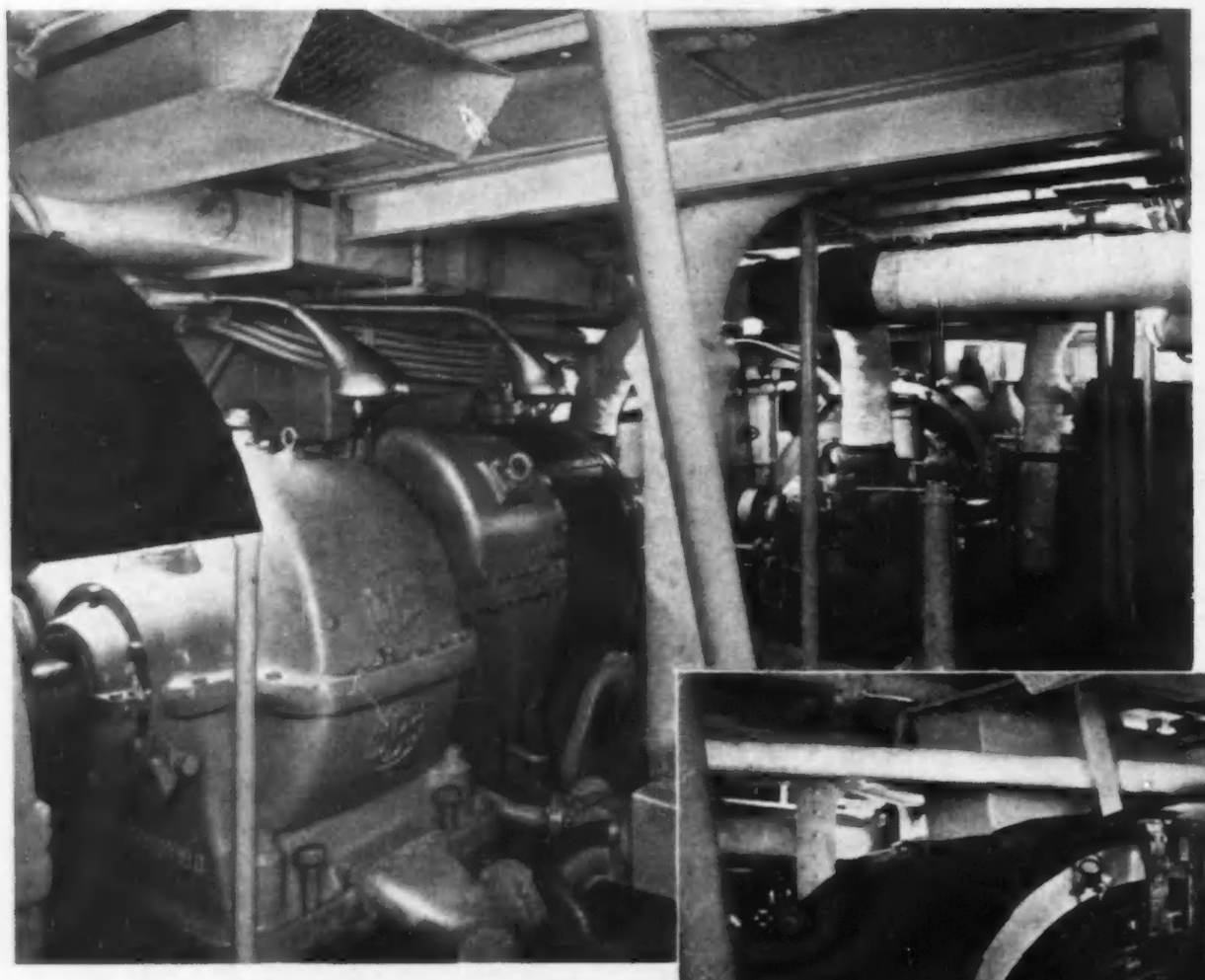


Fig. 15 (*Above*).—**Two of the auxiliary turbines, each driving a 750 kW generator.**

Fig. 16 (*Right*).—**Near view of one of the 750 kW, 220-volt, D.C. generators.**

Heating.
Lighting.
Galley.
Deck auxiliaries.
Propulsion excitation circuits.
Engine room auxiliaries.
Various other auxiliary services.

The centre panel carries paralleling voltmeters, overload relays and definite time relays, used in connection with the non-essential circuit tripping scheme (see following sections), while the two adjacent panels on each side are each equipped with a Salford 4,000 amp. triple pole line contact circuit breaker, arranged for electrical operation under push button control; also pilot lamp, field rheostat and the reverse current relay. The remaining 8 panels on the left hand side (facing the board) are equipped with meters and 13 Salford line contact circuit breakers ranging from 400 to 1200 amps., controlling deck auxiliary circuits, propulsion excitation circuits and various auxiliaries. Below the circuit breakers are mounted the G.E.C. "Plural Starter" contactor units controlling auxiliary engine room auxiliaries.

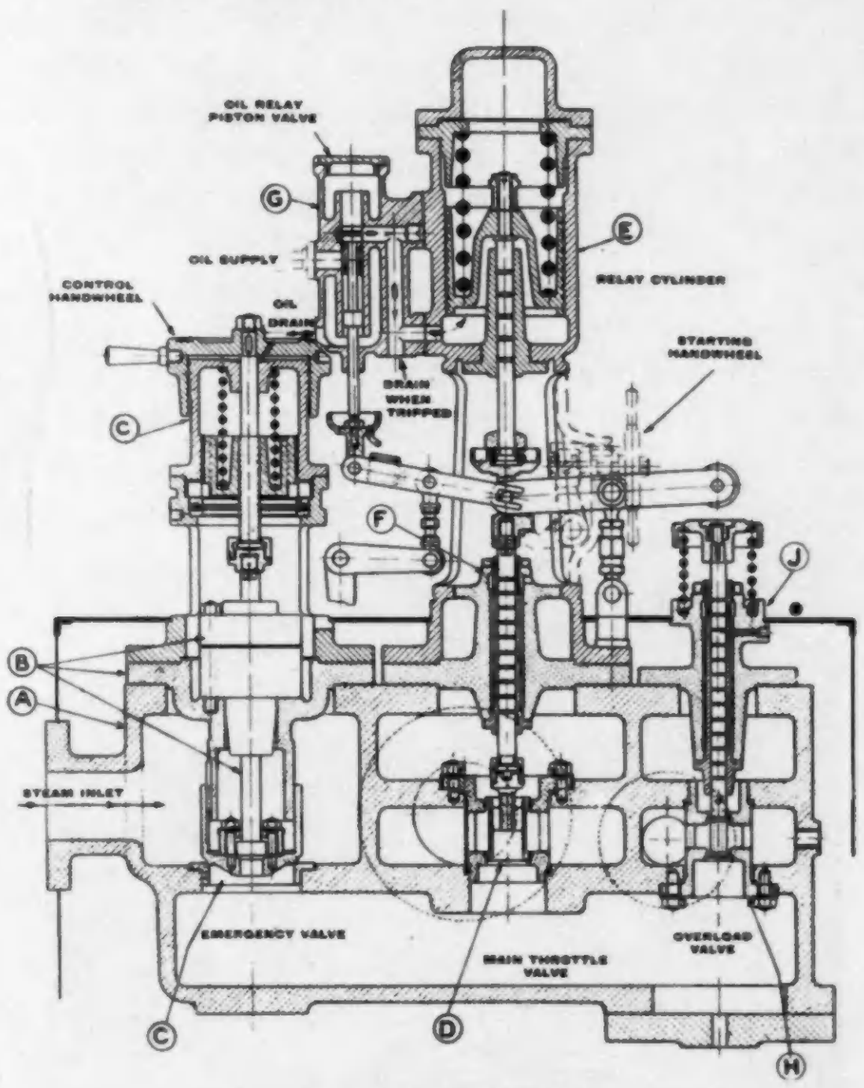
The 8 panels on the right are equipped with meters and 10 line contact type Salford breakers ranging from 300 amps. to 2,000 amps. Two of these circuit breakers supply two sets of busbars, to which are connected a number of switches and fuses controlling "non-essential" engine room circuits, while the remainder control various distribution circuits. In the lower part of the board two panels carry fuses and changeover switches for the steering gear motors. Each circuit provided with a meter also has sockets into which may be plugged a recording ammeter.

PLURAL STARTER EQUIPMENT.

A further switchboard, fig. 19, is mounted in the main engine room and carries a second complete "Plural Starter" equipment to deal with main engine room auxiliaries, distribution switchgear for engine room circuits together with two circuit breakers with changeover switches. The G.E.C. "Plural Starter" system is of a particularly interesting nature, the main principle being that one starter only is used for a number of motors, the starter and associated apparatus being located at the main switchboard. In this way a considerable saving in floor space in the engine room is effected.

The apparatus employed may be divided into three parts :—

(1) A control unit for each motor mounted with the motor.
(2) The common starter which is conveniently accommodated on one of the panels of the switchboard on which the starting contactors are mounted.
(3) Two line and one starting contactors for each motor, mounted on switchboard panels together with the tripping devices or relays which are required.



REFERENCE TABLE.

A	Steam chest.	**E**	H.P. relay cylinder and starting gear.
B	Metallic packing, baseplate and spindle.	**F**	Baseplate.
C	Emergency valve and control details.	**G**	Piston valve.
D	Throttle valve and cage.	**H**	Overload valve.
		J	Overload valve gear.

Fig. 17.—Section through steam chest, emergency valve and relays of the 750 kW auxiliary turbines.

The control unit consists of start and stop push buttons. isolating links, a shunt regulator; also ammeter and pilot lamp are provided. It should be noted that the control unit entirely obviates any need for a terminal box on the motor, the control unit being mounted on the motor itself.

The starter is of the motor operated drum type. The drum is mounted on the front of one switchboard panel and the pilot motor on the back. This form of starter is adopted because it is essential to use a type capable of functioning satisfactorily over a wide range of current. The drum is arranged to make a complete revolution at each start, and in order to give a longer starting period for the larger machines, the motor is provided with two independent field windings. One of these is a light series winding so designed that the starting time given by it alone is short and suitable for the smallest machine. The second

Fig. 18.—Main D.C. switchboard in auxiliary engine room.

9109-15

Fig. 19.—G.E.C. "Plural Starter" switchboard in main engine room.

4109-8

winding acts in conjunction with the first, and is connected across the starting resistance. When starting a large machine the sustained voltage drop

across the resistance energises the winding and strengthens the field, giving a proportionally longer starting period.

The resistance is designed to have a total ohmic value high enough for the smallest machine, while the later steps are of sufficient section to deal with

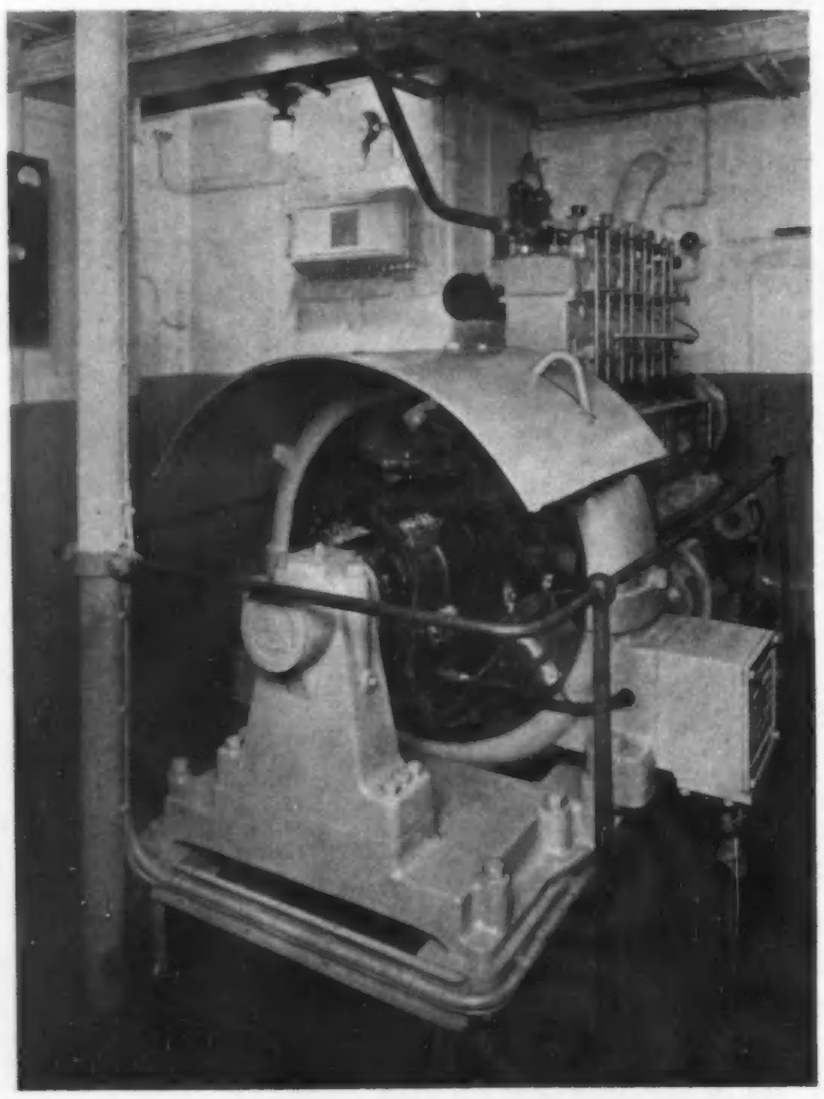


Fig. 20.—45 kW emergency generator driven by Fiat oil engine.

two or three times the current of the largest machine. By suitable grading it has proved possible to start machines smoothly which vary in horse power in the ratio of 10 : 1. The line and starting contactors are of the usual G.E.C. standard pattern and call for no particular comment.

When the "start" push button is operated two of the contactors close, and connect one terminal of the machine to the line while the other is connected to the starter. Simultaneously, the drum starter is set in motion by the pilot motor and the starting resistance gradually cut out, until finally the third contactor closes, so that the machine is connected to both poles of the supply. As soon as the starting operation is thus completed, the starting contactor is opened, and the operation may be repeated for another machine.

During and after starting, the motor is fully protected by the overload relay which, on tripping, opens both poles of the motor circuit. The system is arranged to work in conjunction with the "non-essential" circuit tripping scheme and certain of the motor panels are provided with shunt tripping coils on their overload relays. Suitable interlocks on the starter render all the "start" buttons inoperative while the starter is actually in use.

Two complete plural starter systems, as described above, are installed in the "Monarch of Bermuda" of which the engine room set deals with 12, and the motor room set with 17 motors. Each installation is provided with a standby starter which may be brought into action by a changeover switch. Moreover, each starter may, in emergency be operated manually.

NON-ESSENTIAL CIRCUIT TRIPPING SCHEME.

The ship's auxiliary supply as a whole is protected by the "Non-essential" circuit tripping system. Each circuit and each motor of the "Plural Starter" installations is provided with a shunt trip connected to one of two busbars. Should the auxiliary generators become overloaded the two busbars are successively energised by timing relays, the first after an interval of 5 seconds from the occurrence of the overload, and the second after a further interval of time. Circuits of secondary importance—*e.g.* winches, certain ventilating units and part of the illumination—are thereby dis-

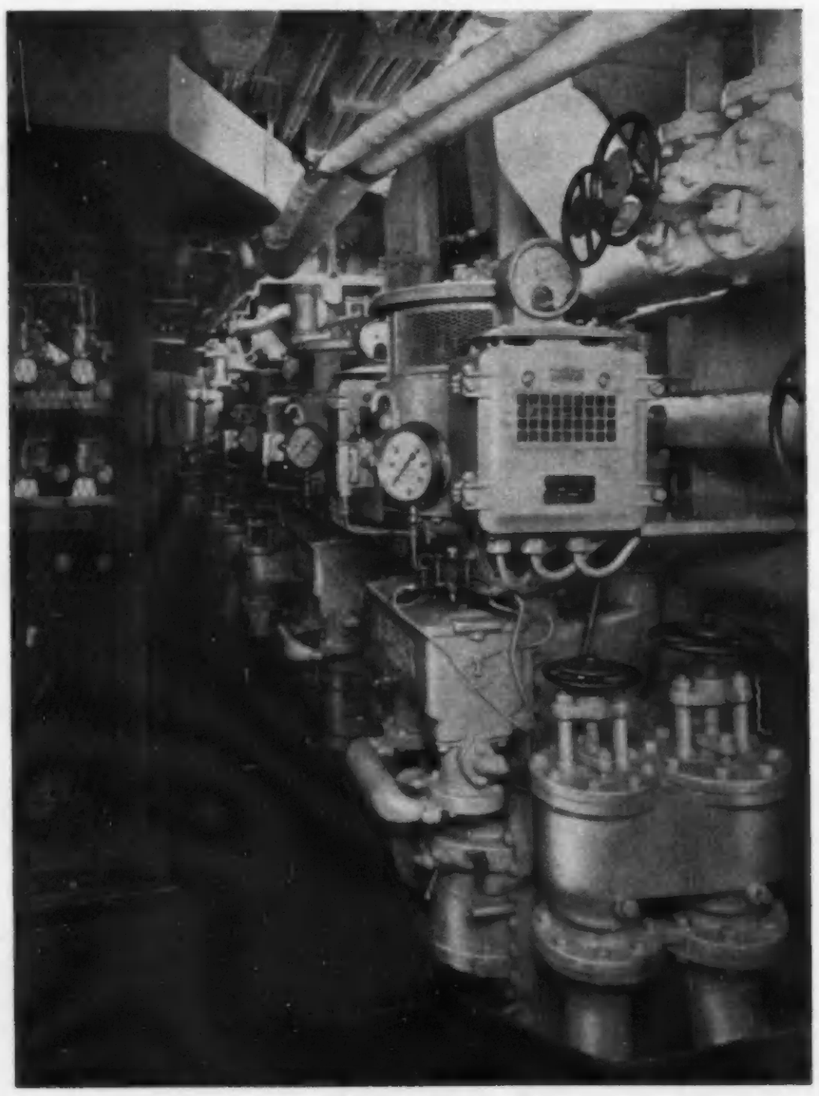


Fig. 21.—General view of some of the auxiliary pumps controlled on the "Plural Starter" system.

connected when the first busbar is energised. If the overload still persists a further group of circuits is disconnected by the energising of the second busbar, leaving alive only those circuits supplying the most vital services of the ship, such as navigation, engine room, and skeleton lighting throughout the ship, steering gear, propulsion excitation, wireless, etc.

Under certain conditions this arrangement results in a considerable saving in running costs, as it is possible to run up to the limit of each generator's capacity without endangering the continuity of supply to essential services, with the saving, in many instances, of the operating cost of one generator.

EMERGENCY PLANT.

For maintaining a supply of power adequate for essential services in cases of emergency, a Fiat oil-engine driven D.C. generator of 45 kW capacity, fig. 20, is installed on one of the upper decks well above the water line. The output of this generator is controlled by 3 panels of a 6-panel emergency switchboard situated in the same room, the other three panels controlling a "panic" battery and its associated distribution circuits. The change-over of the panic lighting circuits from the emergency busbars to the battery is entirely automatic and takes place on failure of the busbar voltage.

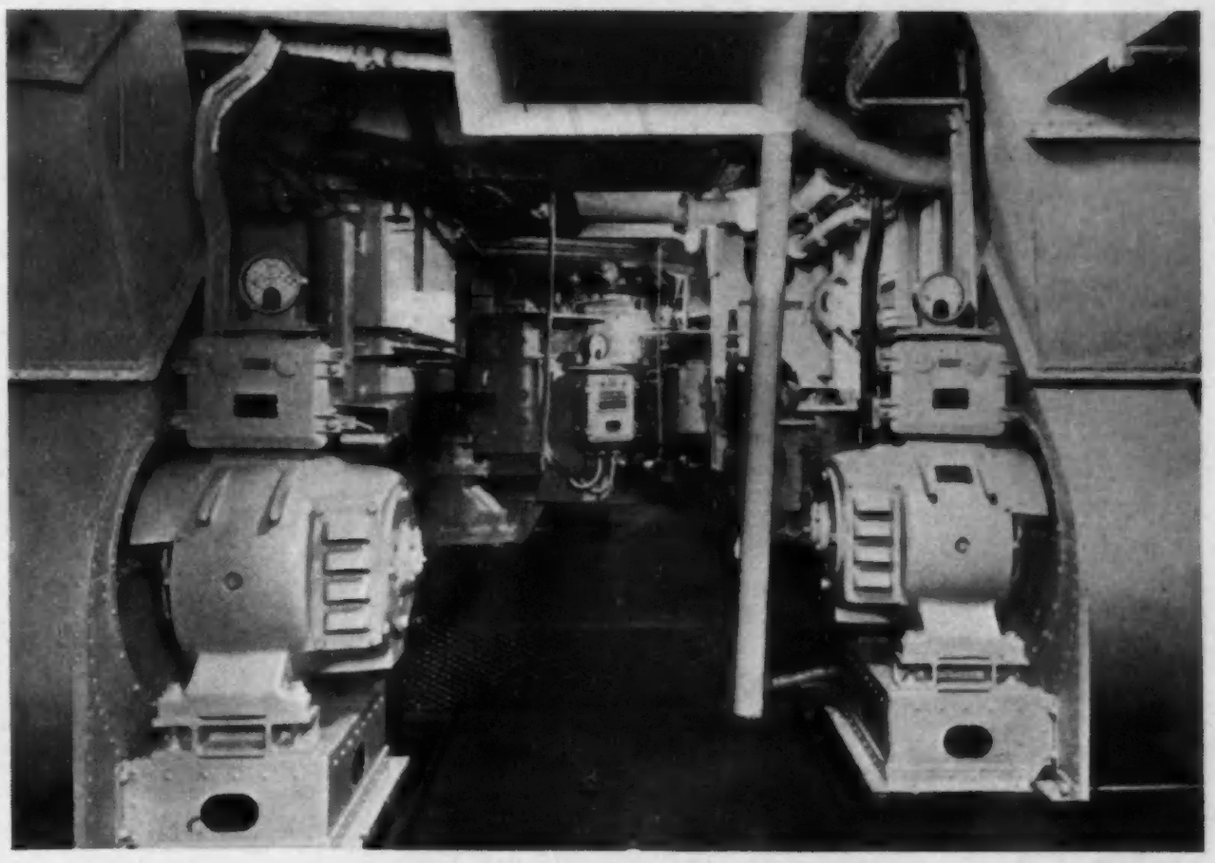


Fig. 22.—Auxiliary pumps and ventilating unit on the port side.

9109-26

ENGINE ROOM AUXILIARIES.

Mention must be made, before leaving the description of the engine rooms, of the large number of electric motors employed for driving all the auxiliary equipment such as ballast, bilge, sanitary, fresh and salt water pumps, turning gear, forced lubrication, extraction and circulating water pumps, etc. All these are driven by marine type drip-proof motors of various sizes and speeds, ranging down from 160 h.p. The motors comply in every respect with the specifications of the appropriate British and American authorities, one particular feature being the impregnation both before and after winding of all coils, a process which renders them fully capable of withstanding the effects of atmospheric conditions prevailing in the tropics.

Most of these units are of the vertical spindle type and are controlled on the "Plural Starter" system previously described, the "start" and "stop" push buttons being mounted on the frames of the motors. Views of some of the auxiliary pumps are shown in figs. 21 and 22.

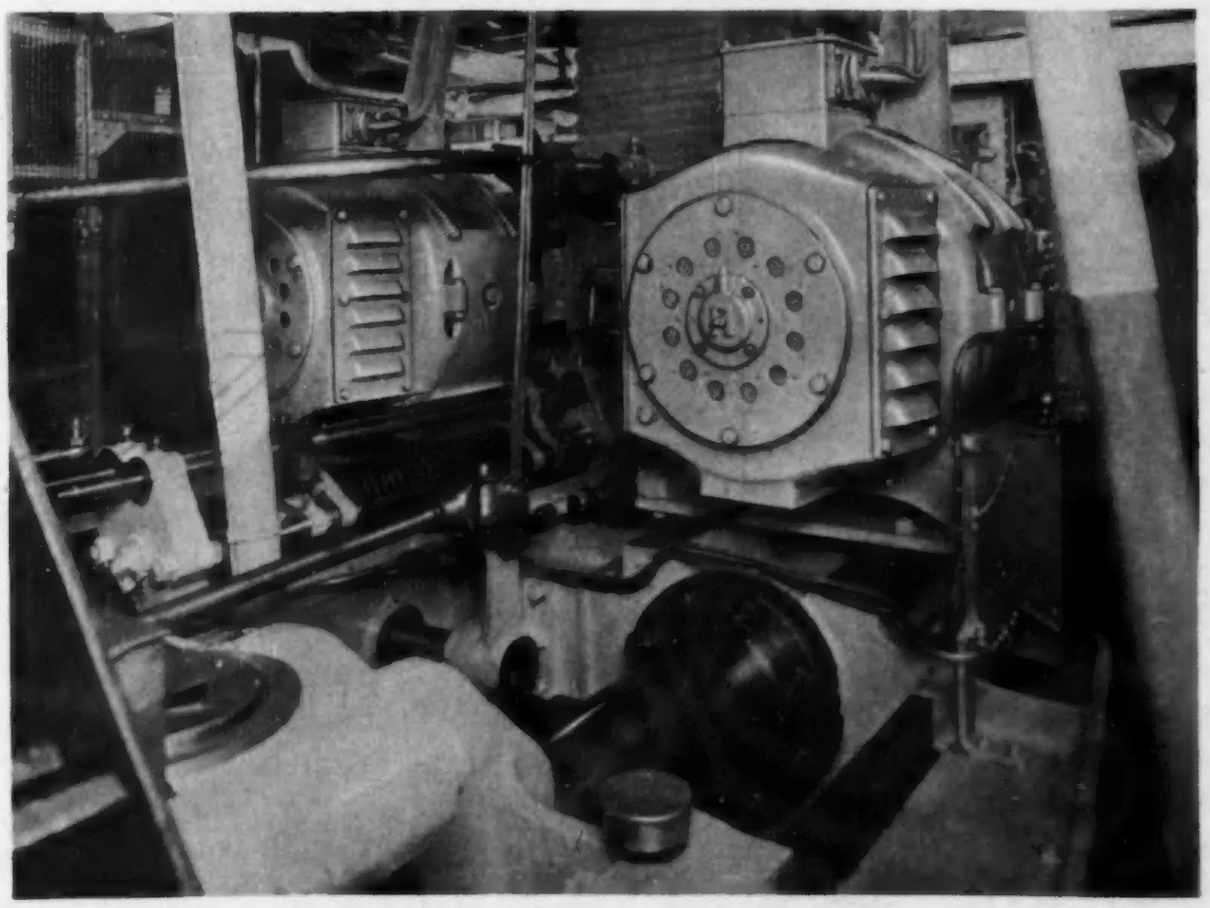


Fig. 23.—Steering gear driven by 42 h.p. motors.

9109-29

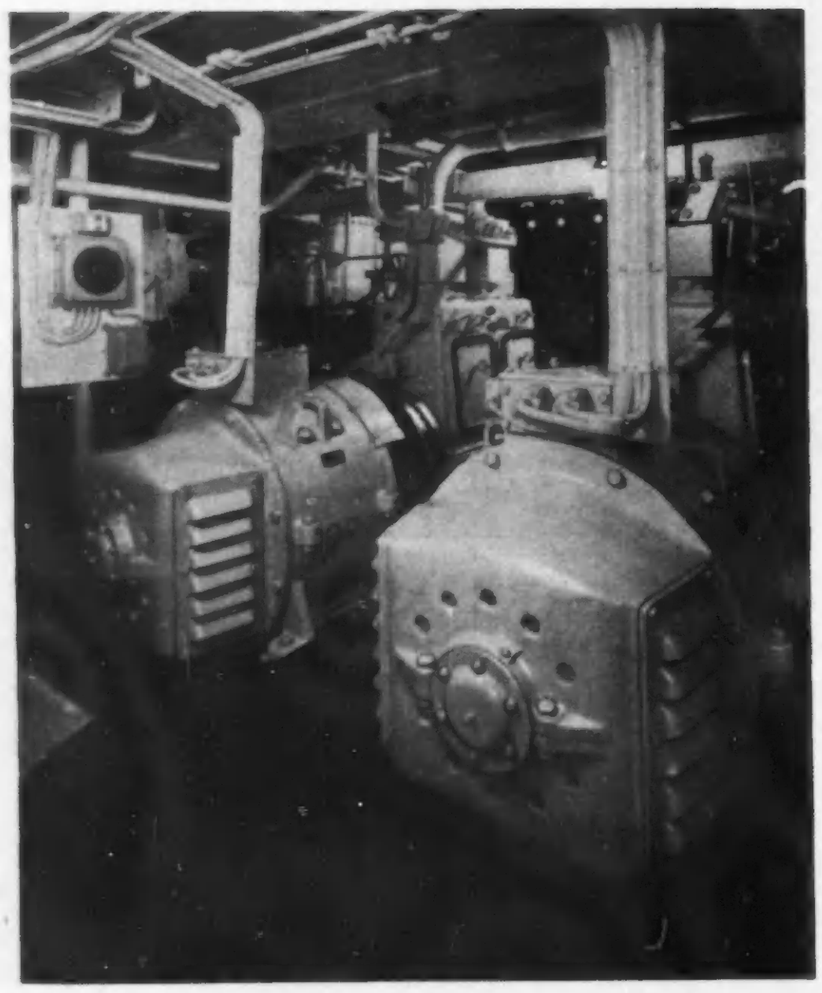
STEERING GEAR.

Owing to the confined channels of Bermuda Harbour, the design of the steering gear has received special attention. The electric hydraulic gear supplied by Brown Brothers & Co, Ltd., of Edinburgh, is of the 4-cylinder type with two main and one emergency pumping units, each of the main units consisting of a 42 h.p. motor driving a Williams-Janney variable delivery pump, fig. 23.

The pump controls which are operated from the bridge by Brown's hydraulic Telemotor are so arranged that whichever pump

is in action delivers oil under pressure to the hydraulic cylinders, the rams of which are connected to the rudder stock through a crosshead and cause the rudder to move in exact response to the movements of the steering wheel. Each of the main pumping units is capable of meeting all ordinary steering requirements and, normally, one unit is in reserve, arrangements being provided for changing instantaneously from one unit to the other, or for running both together in close waters.

The emergency pumping unit, driven by a separate 7½ h.p. motor, is operated from the ship's panic battery and is arranged to come into action



9109-24

Fig. 24.—Main refrigerator compressors driven by 67 h.p. motors.

automatically if the supply to the main motors should fail, and to be interrupted automatically as soon as the main supply is restored.

The main motors are controlled by contactors operated by "start" and "stop" push buttons provided in the wheelhouse.

REFRIGERATOR EQUIPMENT.

A vessel of the size of the "Monarch of Bermuda" must of necessity carry a large amount of perishable foodstuff for consumption during the voyage, in addition to its refrigerated cargo. A large refrigerating plant has therefore been installed by J. & E. Hall Ltd., involving the use of over 20 motors ranging in size from ½ h.p. up to 67 h.p. Most of these motors are controlled from a separate slate panel switchboard installed in the refrigeration machine room. The motor-driven compressors are shown in fig. 24.

DECK MACHINERY.

The deck machinery, which has been supplied by Clarke Chapman & Co. Ltd., comprises a powerful naval type windlass, four warping capstans and four winches.

The windlass is arranged with two vertical spindles carrying the cable lifters for handling 3⅛

Fig. 25.—150 h.p. motor and Ward-Leonard set for driving windlass.

9109-45

inch cable. Two additional spindles each carry capstan heads for warping purposes so that the complete gear not only handles the anchors but also functions as a forward warping capstan.

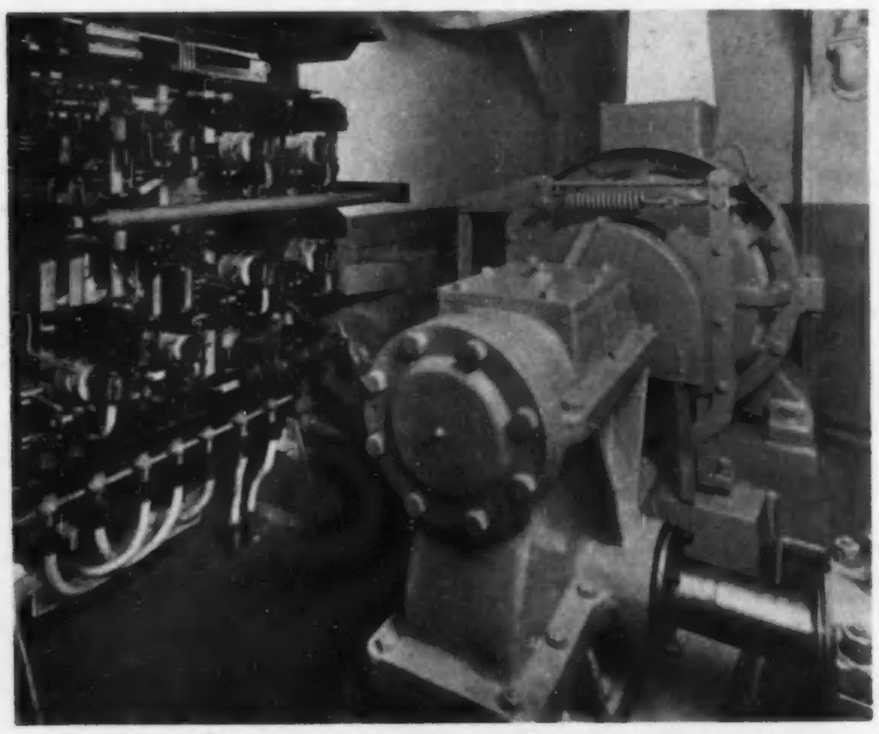


Fig. 26.—75 h.p. motor and control gear for capstans.

9109-46

The vertical shafts are driven through worm spur and bevel gearing by a 150 h.p. enclosed ventilated motor, fig. 25, running at 400/900 r.p.m., which is placed below the deck. The control of the motor is effected by a booster control system, expressly designed for use with deck auxiliaries, the current supply being drawn from the ship's 220-volt mains. The system embodies protective

features against overload and gives a characteristic similar to that obtained by steam gear, but is much more economical in power consumption. It is a distinct advance over the ordinary contactor controlled capstan as there are no main resistance losses, thus giving a higher overall working efficiency. Moreover, owing to the use of a higher voltage, *i.e.* 440 volts, the machines are smaller in size.

The motor-generator set, together with the starting panel, is mounted below deck beside the main motor, and is of the enclosed ventilated type.

Control is effected by means of a master controller on the top deck near the capstan heads, a starting switch for the motor-generator set and also an ammeter connected in the main motor circuit which is calibrated in tons pull for both warping capstans and the cable heads.

The cable lifters are capable of raising 28½ tons at 38 ft. per minute and the capstans 10 tons at 130 ft. per minute.

Four warping capstans are also installed, two being placed forward and two aft. One of the latter is arranged as a cable capstan for handling the stern anchor and is provided with dual control for operation from two decks. The duty of the capstans is to exert pulls of 15 tons at 45 ft. per minute, 13 tons at 60 ft. per minute, 3 tons at 160 ft. per minute and slack at 240 ft. per minute. Each capstan is driven through worm and bevel gearing by a 75 h.p. 250/1000 r.p.m. enclosed ventilated

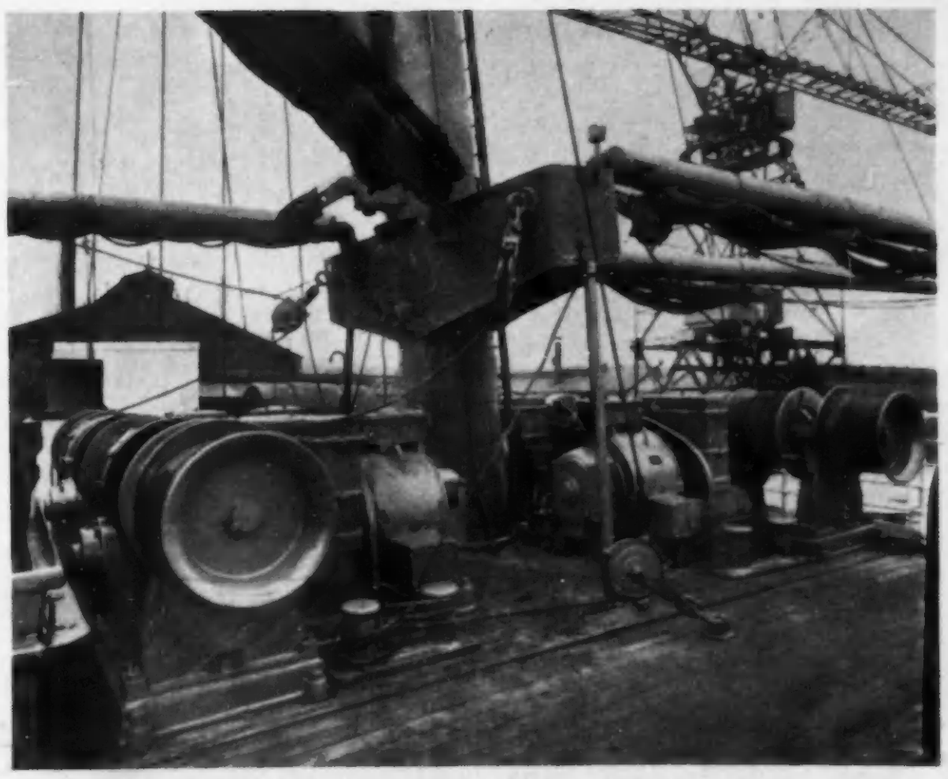


Fig. 27.—Winches on deck driven by 24 h.p. motors.

9109-72

motor placed below deck, fig. 26, control being carried out by the booster control method as in the case of the windlass.

For cargo handling, four silent worm geared winches have been supplied arranged in pairs so that the individual machines forming each pair can be coupled together by means of a heavy derrick barrel for dealing with maximum loads of 15 tons at 30 ft. per minute. Separately, each winch is designed for a duty of 3 tons at 130 ft. per minute, 1½ tons at 160 ft. per minute, 1 ton at 300 ft. per minute and light hook at 400 ft. per minute, and is driven by a 24 h.p. motor, fig. 27. The control gear is of the contactor type and is placed in deck houses near the winches, watertight master controllers being mounted on each winch.

When two winches are coupled together in the manner indicated, both winches are controlled from one master controller, while if required, they can also be operated from a small portable controller which is strapped to the shoulders of the operator

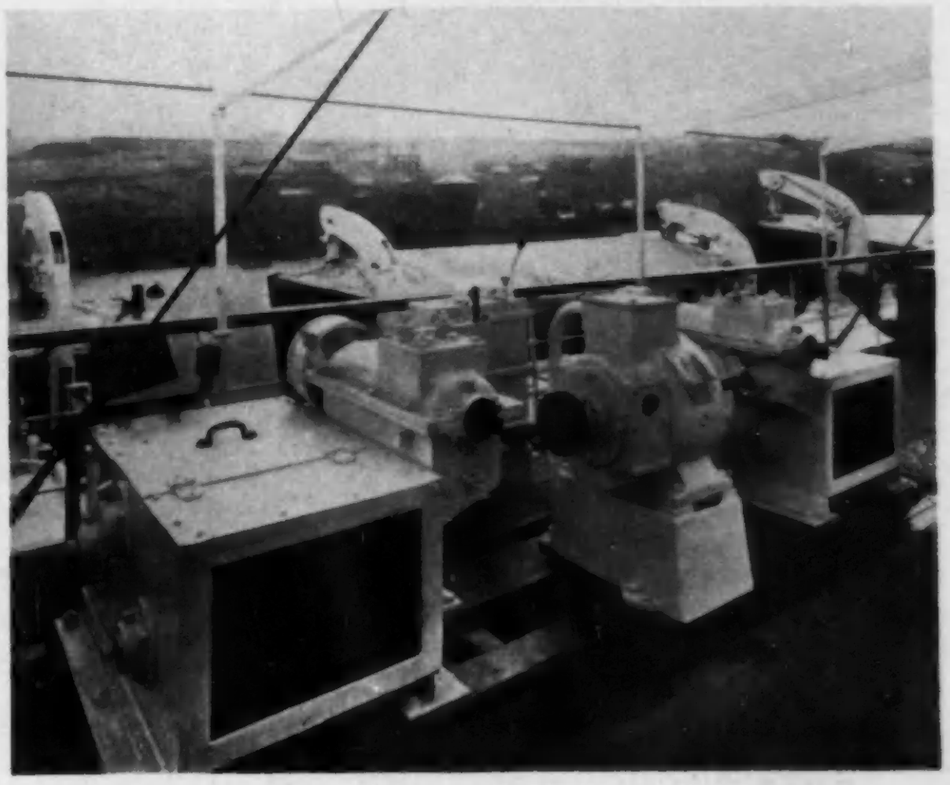


Fig. 28.—Boat davit gear driven by 15 h.p. motors.

9109-73

who is thus free to move about and, at the same time, to control the winches while supervising the handling of the cargo.

The raising and lowering of the accommodation ladders is accomplished by four small electric winches supplied by Brown Brothers & Co. Ltd., each being driven by a 7 h.p. motor.

Other deck machinery which is driven electrically includes the davit gear for the 14 Fleming lifeboats and the two launches installed on the vessel—this number being sufficient to accommodate every soul on board. The type of davit used for lowering the boats is of the automatic gravity type, while the boats are raised by electrical power involving the use of eight 15 h.p. marine type motors as shown in fig. 28.

VENTILATION.

The unusually extensive scheme of ventilation adopted on the "Monarch of Bermuda" represents a very successful attempt to counteract the effects of the very humid atmospheres encountered, particularly in the Gulf Stream which is crossed on the New York—Bermuda route. The frequency with which the air is changed inside the ship exceeds by a very

large margin the requirements of British and foreign authorities.

While the various cargo holds, "tween decks" and some of the less important store rooms are ventilated naturally by the usual cowl ventilators, the whole of the accommodation is ventilated by the Thermotank system employing a total of 126 ventilating units each of which incorporates a fan driven by a small silent marine motor. The control of 60 of these units is centralised on a starting panel, from which each unit can be started or stopped by a push button as illustrated in fig. 26. In addition to this, all cabins, saloons, etc., are provided with Magnet ceiling fans or Gyro 2-speed fans of which a total of approximately 600 has been supplied.

For the ventilation of the engine room, which was carried out by the British Aerotechnical Co., 8 Witton motors totalling 65 horse power are employed.

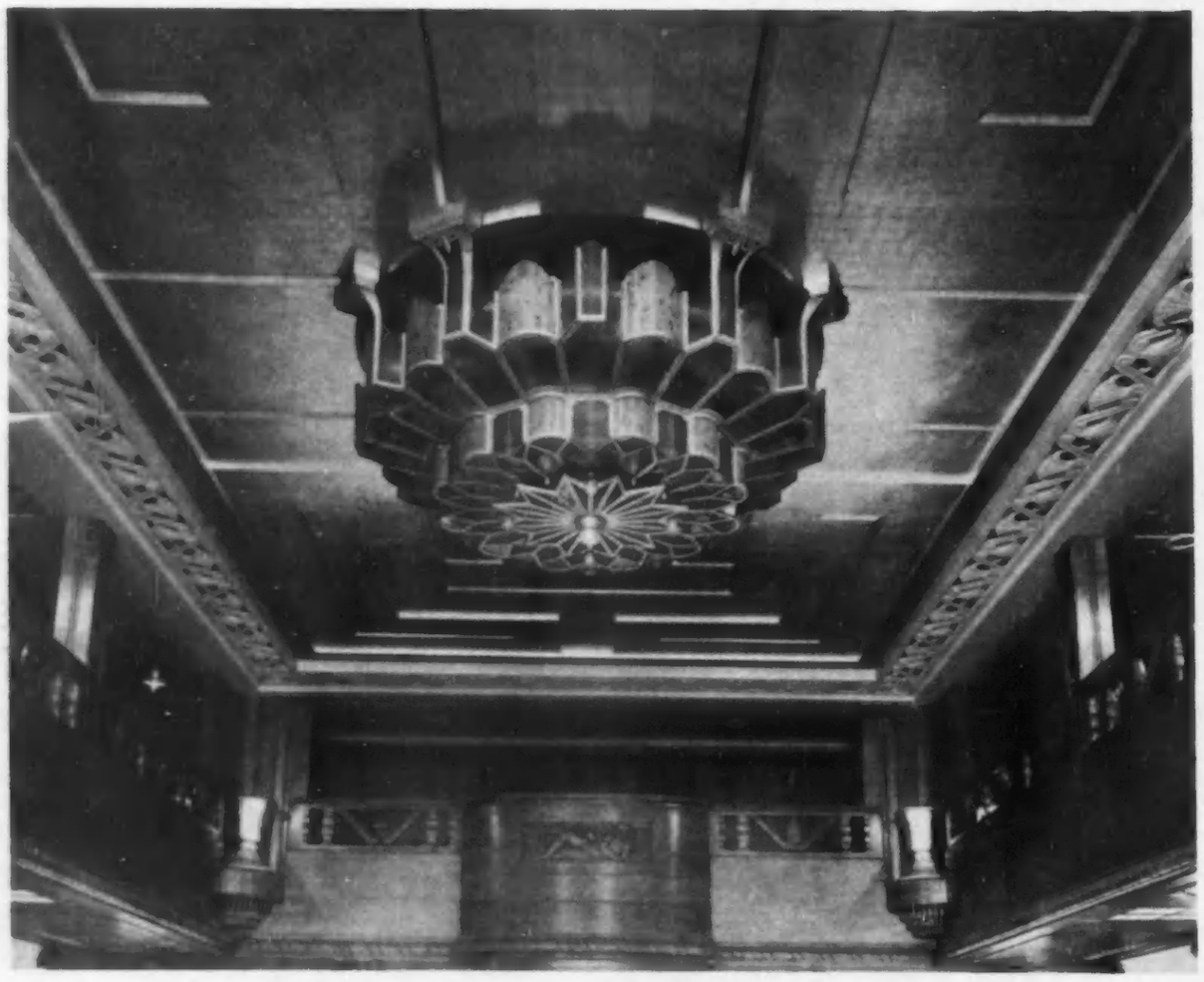


Fig. 29.—Central lighting fitting in dining saloon. Weighing approximately half a ton, the fitting is 9ft. in diameter and is built almost entirely of glass.

ILLUMINATION.

The illumination of the various public rooms of the "Monarch of Bermuda" affords a striking example of the high degree of excellence obtained by modern scientific methods of lighting. Each of the beautifully decorated rooms is provided with a lighting scheme, which not only gives an abundance of light whenever required, but, in addition, harmonises with the scheme of decoration adopted. Such results have only been rendered possible by the close co-operation which has existed between the ship's architect, decorative consultant and contractors, shipbuilders and the illumination experts of the G.E.C. during the preparation of the schemes. In each case it was determined first, the amount of light which would be required, and, afterwards, whether it should be supplied direct from the source of light, or by indirect or semi-indirect methods.

Concealed lighting has been employed in most instances and the rooms are thus suffused with an even glow, restful to the eyes but at the same time providing adequate illumination. Space prohibits a detailed description of the whole of the equipment which involves the use of some 5,000 fittings and 20,000 Osram lamps, but mention should be made of a few of the outstanding features of the scheme.

The first-class dining saloon, being very large and having a low ceiling, presented a difficult lighting problem which was most successfully solved by the decorative architect who split up the lowered ceiling into numerous coffered panels, each of which is lighted by mirror and opal lined cornice reflectors. This method of indirect lighting, besides giving a pleasing even diffusion of light with

Fig. 30.—General view of lounge, showing system of illumination.

entire absence of glare, has the effect of heightening the ceiling.

The main feature of the room, however, is the central lighting fitting, fig. 29. At this point the higher ceiling level provided an opportunity to install a decorative fitting of a type and size probably unique in ship lighting. The fitting installed is approximately 9ft. in diameter and is built almost entirely of glass, the whole weighing nearly half a ton. The glass used is a lightly obscured peach-coloured plate mounted in a gilt metalwork frame of rich design. This lighting is further augmented by the provision of sixteen flush laylights, 44 sidelight grilles and 117 table standards. The main lighting is controlled by an electrically operated dimmer.

The magnificently decorated lounge, fig. 30, with its gallery is used, on occasion, for showing talking pictures and stage plays. All the lighting is therefore controlled by an electrically operated dimmer which is governed from the cinematograph room and the stage switchboard.

The general illumination is provided by 85 special recessed laylights, each approximately 2ft. square and fitted with tinted glassware. Rows of concealed Pearl Osram lamps are arranged indirectly to illuminate these laylights. The combination of this method of lighting and the barrelled false ceiling which was shaped to the design of the G.E.C. illuminating engineers results in an even illumination which could not be obtained by direct flooding.

Fig. 32.—General view of Smoking Room.

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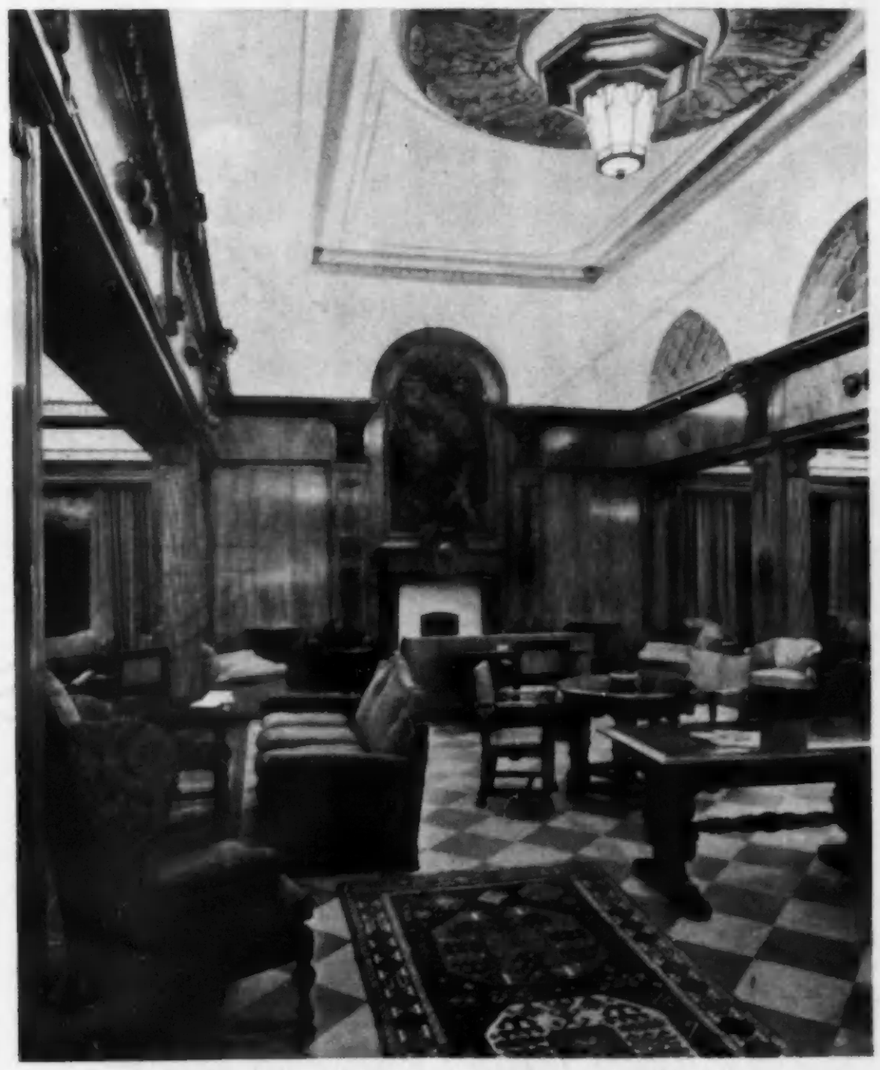

Fig. 31.—Smoking Room with concealed lighting and central fitting.

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Auxiliary illumination is obtained by the fluted cove lighting running round the whole room and the outboard glass cornice lighting under the galleries.

A very complete stage lighting equipment has also been installed, giving a full range of lighting effects.

Concealed lighting is employed in the Smoke Room, fig. 32, Library and Writing Rooms, fig. 33. It is augmented by particularly attractive ornamental units, fig. 31 showing one of these installed in the Smoke Room. The lighting in the Verandah Cafe is shown in fig. 34.

The most ambitious scheme of lighting on board, however, is that of the Dance Hall, fig. 35, and is the most comprehensive system ever applied to the ballroom of a ship. Three-colour lighting is employed in the many ceiling and wall panels, the control of which is in the hands of the musical director on the musicians' platform. Each of the two main ceiling panels is skilfully painted to represent the sky. By two alternative systems of lighting the sky can be illuminated by a luminous sun surrounded by an ornamental sunburst, or by an illuminated moon with numerous twinkling stars. The central feature of the Dance Hall consists of two glazed columns on either side of the musicians' platform. Rainbow hued lights pass slowly over the main

panels of the columns, the colours being controlled by an operator. It is thus possible with the individual dimming controls provided, to produce an almost unlimited number of lighting effects.

Both of the swimming pools are equipped with specially designed under-water flood lights which

Fig. 33.—Writing Room.

produce a very fascinating sparkle in the water, especially when a diving display is in progress.

PASSENGER LIFTS.

The electric passenger lifts installed in the "Monarch of Bermuda" are in keeping with the high-class decorative schemes chosen for the ship.

Fig. 34.—Verandah Cafe.

These lifts, of which there are 13 altogether, including general service lifts, were supplied and installed by The Express Lift Co., Ltd., (a subsidiary company of the G.E.C.), and are typical of a great number of marine lift installations which the Company has executed for liners and warships. All the lifts are driven by "Witton" motors, the lift speeds varying from 150 ft. per minute in the case of the three passenger lifts, fig. 36, down to 60 ft. per minute in the case of the baggage and mail transporter. Each of the four cargo lifts, fig. 37, is capable of raising 1½ tons at a speed of 90 ft. per minute.

All the lifts are automatic in action and are controlled by push-button.

GALLEY EQUIPMENT.

The G.E.C. electrical cooking and heating equipment installed in the Q.T.E.V. "Monarch of Bermuda" is unique in the true sense of the word. Some idea of the extent of this portion of the electrical equipment of the vessel may be gathered from the fact that the maximum load which may be required for cooking and heating alone is 1,000 kW.

One of the first requirements of cooking and heating apparatus for use at sea is that it shall be of robust construction in order to withstand the severe

Fig. 35.—Dance Room, showing decorative lighting. The "sun" in the centre of the ceiling is surrounded by painted cloud effects and twinkling stars.

operating conditions under which it is employed. Simplicity of design and standardisation of renewable components are also of primary importance. Thus, in the particular equipment on the "Monarch of Bermuda," not only is the apparatus exceptionally rigid in construction, but also the ratings of all cables and switches have been kept at a low value, while careful consideration has been given to the standardisation of elements, switches, fuses, etc., so that the number of different types of spares necessary have been reduced to a minimum.

The equipment is installed in the main galley and pantries, bakery and confectionery shops, deck service pantries, 1st and 2nd class dining saloons, cabins, crew's galley, hairdresser's and dispensary.

The main galley equipment comprises :

2—8-oven island ranges.
2—18ft. 6in. hotpresses with carving tables.
1—13ft. oin. hotpress with carving table.
2—6ft. 6in. hotpresses.

1—3-pan fish fryer with hot cupboard.
1—3 compartment griller with hot cupboard.
2—20 gallon water boilers.
2—salamanders.
3—24in. by 18in. hotplates.
5—30in. by 15in. hotplates.
4—automatic toasters.
3—2-way waffle irons.

ISLAND OVEN RANGES.

Each of the two island ranges, fig. 39, consists of 8 ovens, each 26 inches wide, 26 inches deep and 21 inches high, having a maximum loading of 6 kW per oven. The heating elements are mounted at the sides on frames which can be removed easily and quickly for replacement purposes. The elements employed comprise porcelain panels carrying the heating coils. The elements are connected two in series. Monel metal is employed for hygienic reasons in the construction of the oven interiors, grids, pans and browning shelves, while the main structure of the range is built up from $\frac{3}{16}$in. and $\frac{1}{4}$in. mild steel plate, the doors being of cast iron. Asbestos lagging, 2ins. thick, is used to confine the heat to the oven interiors. A total of forty "Magnet" 12in. and 8in. embedded type hotplates are arranged in groups of four on each of the hobs.

An interesting feature of these ranges lies in the fact that the loading and method of mounting the hotplates is such that, while adequate heat is available for boiling and frying, undue overheating and the probability of consequent premature failure of the elements are eliminated. A further feature is that all the internal wiring is taken to terminals at each end of the range and thence through trunking to the two control panels mounted on the canopy above, thus leaving the hob free of all obstructions. Above each range are mounted two substantial racks for carrying the various pots and pans, and at each end are fixed draining trays for strainers, ladles and the like.

9609-49

Fig. 37.—Driving motor and control gear of goods lift.

In order to avoid confusion, individual switches and pilot lights on the control panel are not only clearly labelled, but the pilot lights for each section show a different colour, that is, red for each oven, green for each of the hotplates along the centre of the range, and blue for each hotplate along the side of the range.

9609-93

Fig. 36.—One of the "Express" passenger lifts.

HOTPRESSES, ETC.

The general construction of all the hotpresses is similar. The tops are made of monel metal and the body of 14 S.W.G. steel plate. Tubular elements are provided for the bottom heat and panel elements for the top heat. This system is standard to all hot cupboards and ranges.

The three large hotpresses are fitted with carving dishes and sauce tureens while the interiors are divided into sections, each section being subdivided to accommodate one revolving 3-way plate creel. In this way each carver is provided with accommodation in the cupboard for plates for his own needs. Mounted in the top immediately behind each dish are two pure nickel sauce tureens, while at each end of the two larger hotpresses a Bain Marie carrying additional tureens is provided. Telescopic lifting gear for the carving dish covers is fitted. This is fixed to the dish cover,

and by means of the counter balance provided, enables the cover to be lifted easily. In all cases the elements are arranged for 3-heat control and the necessary switches, fuses and pilot lights are mounted on a separate board on the adjacent bulkhead.

Fig. 38.—Fireplace in second-class Lounge fitted with convector type electric fire.

The fish fryer comprises three pans fitted with a folding lid. The pans, which measure 20ins. by 18ins. by 7ins., are arranged to lift out, for cleaning purposes. Above the pans is mounted a canopy having a white vitreous enamelled lining and carrying a draining rack. The body of the fryer surrounding the pans is adequately lagged, while a heated hot cupboard space is constructed on similar lines to the hotpresses. Here, again, the requisite switches, fuses and pilot lights are mounted on a switchboard on the bulkhead.

The griller has three grilling chambers, each 20in. by 15in. The element coils are carried on porcelain cleats at the top of the chamber and are protected by a suitable guard. For replacement purposes it is only necessary to remove four connections. Each chamber is lined with monel metal and is fitted with a rise and fall attachment, which can be fixed in numerous positions. A fat drawer is fitted below to retain the fats which accumulate during grilling. Above the grills is a hot cupboard divided into three sections and heated in a similar manner to the hotpresses.

Two 20-gallon water-boilers are installed, one on the port and the other on the starboard side of the galley. Each is constructed of copper polished on the outside and tinned inside, while between the inner and outer casings two inches of cork lagging is introduced. Heat is obtained from two 4 kW blade type immersion heaters inserted through the side.

The two salamanders are designed on the lines of the 3-compartment griller. The interiors are fitted with a rise and fall attachment and are lined with monel metal, while the heating coils are carried on porcelain cleats in the top and are protected by a guard. Access to the elements is obtained by raising the top of the salamander. Each element is arranged for single heat and is controlled by a separate "on and off" switch.

Fig. 39.—One of the electric island oven ranges in the main galley.

Hotplates are installed for the purpose of making griddle cakes and scone cakes and for this purpose even heating is essential. Each plate is constructed with a cast iron top and a substantial wrought iron body. The coils are carried on porcelain formers immediately below the top plate, and on "high," "medium" or "low," the heating is uniform over the whole of the surface.

BAKERY AND CONFECTIONERY SHOP.

In the bakery and confectionery shops are installed :—

1—baking oven.
1—pastry oven.
1—24in. by 18in. hotplate.
2—2-way waffle irons.

Each of the ovens is of the double-deck pattern and is constructed along standard marine lines, having fire brick soles, 4ft. wide by 5ft. deep. The tubular heating elements can be replaced without having to open the oven doors.

WARMING PLATES FOR DUMB WAITERS IN DINING SALOONS.

A total of 52 hotplates are installed at various points in the first and second class dining saloons for the purpose of serving hot food direct to the passengers. All these appliances are alike in their construction, the top of each hotplate being of polished steel and the body of polished brass. Standard "Magnet" strip elements are clamped on the underside, the maximum loading of the plates varying according to their size. One standard wattage element, however, is used throughout.

DECK SERVICE PANTRIES.

The deck service pantries are equipped with :—
8—2ft. 6in. bulkhead hot cupboards.
3—2ft. 6in. deck mounted hot cupboards.
3—3ft. deck mounted hot cupboards.
13—Automatic toasters.

The hot cupboards are all double cased, the heating elements being of the tubular pattern, rated at 2.4 kW, 2 kW and 800 watts for the different sizes.

CABIN HEATERS AND RADIATORS IN PUPLIC ROOMS.

Altogether, 402 convector type heaters are installed in the cabins. These heaters have white vitreous enamel end-castings and back plates, the elements being protected by two casings—the outer of which is ornamented by an oxidised silver finish. The loading of each unit is 500 watts, arranged for single heat. Approximately 100 electrically heated towel rails have also been installed and are made of brass tube having a Fescolised chromium plate finish. The heating elements are enclosed in the top and bottom horizontal tubes forming the towel rail.

Electric fires of a more ornamental nature than those installed in the cabins are placed in the public rooms. These fires are of the convector type, fig. 38, and are equipped with 500-watt elements. Each fire is fitted with a bronze framework in which is mounted an artistic glass panel illuminated from behind by lamps.

COMMUNICATION AND SIGNALLING.

The various ways in which electricity is used for communication and signalling purposes on the vessel are full of interest. For communication between passenger and stewards the "Magnet" luminous indicator system is utilised. A call from a passenger is immediately shown by a light indicator outside the particular cabin, while another light

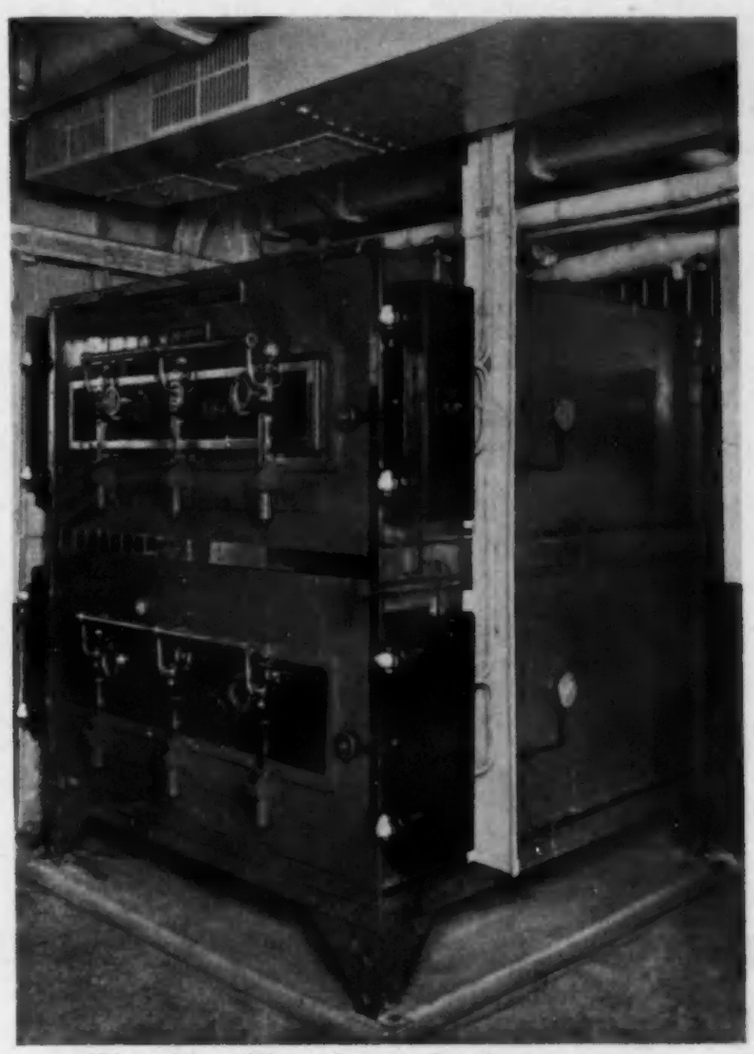

Fig. 40.—Electric confectionery oven.

Fig. 41.—Electric carving table, hot cupboards, etc., in main galley.

indicator is operated at the junction of each branch alleyway with a main corridor. A further signal is given by an indicator in the local pantry. These lights remain on until the call has been given attention.

Another indicator system which the G.E.C. has installed is that for the fire alarms. It is naturally of the utmost importance that, in case of fire, means of giving the alarm should be as perfect as humanly possible. A number of glass fronted alarms are placed in selected positions in the ship which, when operated, cause a luminous indicator situated on the bridge to warn the officer on watch who is also afforded an indication as to the origin of the warning. The lines connecting the various alarm signals to the bridge can also be used for telephonic communication by the simple operation of plugging in a hand telephone.

With the telephone system installed, involving the use of a 100-line telephone switchboard and a large number of telephones, not only is internal communication possible between passengers but also, when the ship is in port, it is possible to connect the system to any type of telephone exchange on shore.

TRIAL RESULTS.

In conclusion, some brief details of the results obtained during the trials of the vessel and her performance during her maiden voyage should be of interest.

The vessel left the Tyne on November 4th, 1931, and carried out preliminary sea-trials off the mouth of the river, proceeding north-about through the Pentlands to the Clyde. During these trials the whole of the electrical machinery, both propulsion and auxiliary, functioned entirely satisfactorily. Although the contracted speed of the ship was 19¼ knots on the mile, she actually obtained over 20½ knots average on the double run. At this speed, necessitating a maximum shaft horsepower of 20,000, the propellers were reversed and all way taken off the ship in the remarkably short time of just over three minutes.

On the morning of the 14th November, she left the Clyde for New York. During the voyage very heavy weather was encountered and for a considerable period of the journey across the Atlantic her speed was reduced to 15 knots with one alternator driving the four motors.

On her first voyage between New York and Bermuda the record for any vessel trading regularly on this run was broken. The official figures are as follows :—

Left Sandy Hook Pilot Station, 10.55 p.m. (G.M.T.) 28/11/31.
Arrived off St. Davids Head, Bermuda 8.30 a.m. (G.M.T.) 30/11/31.
Time elapsed, 33 hours, 35 mins.
Distance, 667 miles.
Average speed for passage, 19.85 knots.
Previous record, 36 hours, 25 mins.
Time saved, 2 hours, 50 mins.

Fig. 42.—Floodlighting of the upper structure and funnels of the Q.T.E.V. "Monarch of Bermuda."

The Experimental Investigation of Vibrations in Turbine Wheels and Blades.

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In this article, which is reprinted from the issue of "Engineering," dated October 30th, 1931, the authors give an interesting account of the methods they have employed of predetermining the critical vibrations of turbine wheels and blades occurring under actual running conditions.

It is believed that the system described represents the first public contribution on the subject where confirmation between experiment and practice has been attained.

THERE are various periodic impulses occurring in a steam turbine, such as disturbances due to the horizontal joint, to stationary blades, and to interruptions of partial admission. Certain parts of the turbine have definite natural frequencies of vibration. Whenever the frequency of a periodic impulse coincides with the natural frequency (or its sub-multiple) of vibration of a turbine part, the latter may vibrate. Such vibrations produce alternating stresses superposed on the working stresses, and if the total combined stresses reach or exceed the fatigue limit, breakage ultimately results. A turbine part may vibrate in a number of ways; fortunately, many of them are not dangerous, the alternating stresses being comparatively small, but there are some possible vibrations which may cause serious danger.

The most important components from the point of view of dangerous vibration are the wheels and blades. It is evident that vibration can be set up in an individual blade, or in a group of blades, or else in the blades and disc as a complete system. Such vibrations may result in the breakage of cover-bands, blades, or wheels; it is therefore of great importance to ensure that dangerous vibrations are avoided. This makes it essential that the natural frequency of any vibration under all conditions of operation should not coincide with the frequency (or its multiple) of any existing periodic impulse.

It will be evident that all of these periodic impulses are multiples of the speed of the machine. In the case of marine turbines or turbo-blowers, the operating speed varies, as a rule, within wide limits; in such cases there are, therefore, no definite periodicities of impulses, and it may become impossible to fulfil the above requirements. In such turbines it is necessary to eliminate certain causes of impulses, such as partial admission; to reduce the intensity of others, such as those on the horizontal joint or due to fixed blades; and, in the case of unavoidable impulses, to reduce the combined stress to which the vibrating turbine part is subjected under working conditions below the fatigue limit of the material.

The extent to which the above measures will be efficacious depends on the actual dimensions of the finished part—in other words, on the design and workmanship, and on the material and the degree of finish, this last factor having a considerable influence on the resistance to fatigue.

In all cases it is clear that the important problem is to establish the natural frequencies of the most important vibrations.

The factors which enter into the vibration of the completed wheel are:

(1) the vibration of the complete wheel as one system; and
(2) the vibration of individual blades, or groups of blades, either axially or tangentially.

Vibration of Blades.

Consider first the vibration of the blades themselves. An individual blade can vibrate in several different modes. It can oscillate in axial or tangential directions, presumably in both cases only in principal planes, which are at right angles to one another. Further, it can vibrate with any number of nodes, theoretically, although in practice up to four or five only are important.

When blades are joined by a cover-band or lashing wire in one or more groups, such groups form systems which have modes of vibration of their own. Special mention may be made of the case where a number of blades are coupled together by a separate cover-band section, independent of other blades in the same row. This system can vibrate either axially or tangentially, or can perform angular vibrations about a radial axis.

Vibration of Stationary Wheels.

In the vibration of discs and wheels different phenomena are exhibited. When the wheel is stationary, the natural frequency at which it will vibrate depends on the particular mode of vibration.

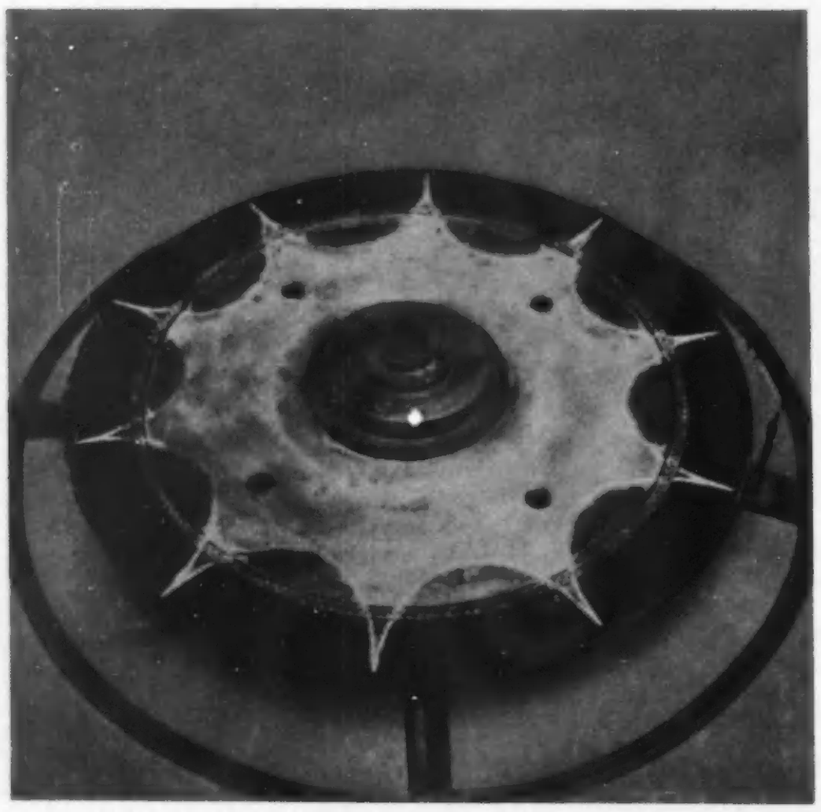

Fig. 1.—Five nodal diameter vibration on bladed turbine wheel.

There is a large number of possible modes, as is evidenced, for example, by the variety of sand pictures produced by Chladni from an oscillating diaphragm. Some modes obtained on an actual turbine wheel are illustrated in figs. 1 to 5.

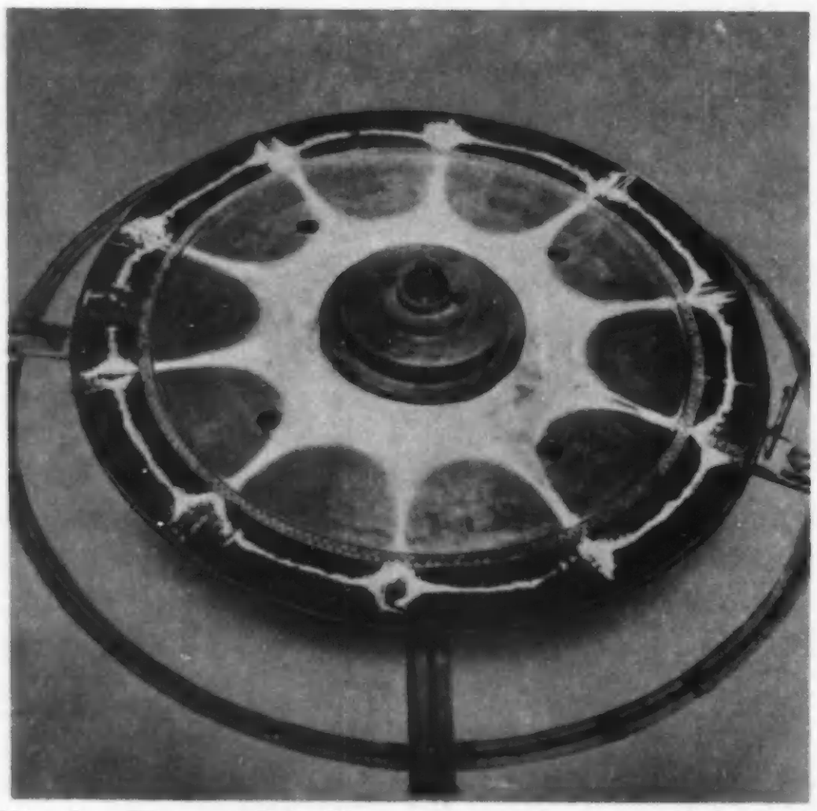

Fig. 2.—Five nodal diameters and one nodal circle on same wheel as shown in fig. 1.

In fig. 1 an ordinary five nodal diameter vibration is illustrated occurring on a bladed wheel, and in fig. 2, in the same wheel, a vibration with five nodal diameters and one nodal circle is shown. In fig. 3, the same type of vibration is shown on an unbladed wheel, and in figs. 4 and 5, which are of academic interest only, vibrations on unbladed wheels are illustrated; in one case there are eight nodal diameters and two nodal circles, and in the other there is a pattern of a more complicated character. It must not be supposed that, in these sand pictures, the places where the sand is not disturbed represent stationary parts of the wheel; actually, the whole of the wheel vibrates from the rim to the hub, with the exception of the mathematical lines of the nodal diameters and circles. The limit of the sand on the wheel indicates the point at which the acceleration of the wheel vertically exceeds that of gravity by some amount which is not very definite, so that the sand does not remain in contact with the wheel during its motion. An interesting, but not particularly important, calculation indicates this point and might here be mentioned. The motion of a wheel has been studied from the analytical

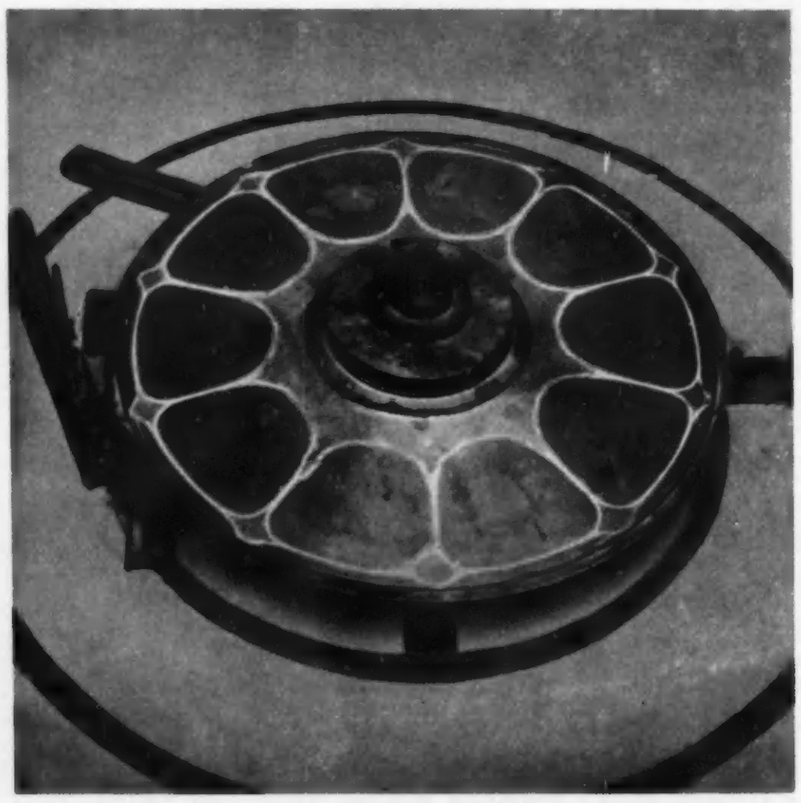

Fig. 3.—Similar vibration as in fig. 2 on unbladed wheel.

viewpoint and an expression obtained for the deflection of the wheel at any instant. If this is twice differentiated with respect to time, the acceleration is obtained, and by making this equal to a constant, the shape of the sand picture can be ascertained. The calculated and experimental curves are compared in fig. 6.

The above "static" tests refer to a stationary wheel on a horizontal test bed, and the frequencies of vibration depend only on the elastic properties of the wheel. Under running conditions, however, centrifugal force and temperature both have the effect of changing the natural frequency of any particular mode of vibration.

Vibration of Rotating Wheels.

The vibrations which have been hitherto considered in this article are of a relatively simple character; when a wheel is set in motion, however, a new conception is necessary to appreciate the

types of vibration which may arise. The sand pictures in the static test are obviously produced by a stationary vibration in the disc; that is, one in which all parts of the wheel are vibrating in phase, and the amplitude varies sinusoidally round the periphery, being positive in one internodal space, negative in the next, and so on. It is possible for a wheel to vibrate in this way during rotation, but it simplifies visualisation to regard the vibration in a slightly different way. It is known that the two "travelling waves"

$$y = a \cos (n\,\theta + p\,t) \quad . \quad . \quad (1a)$$

and

$$y = a \cos (n\,\theta - p\,t) \quad . \quad . \quad (1b)$$

which are of equal amplitude and which travel in opposite directions with the same angular velocity $\frac{p}{n}$,

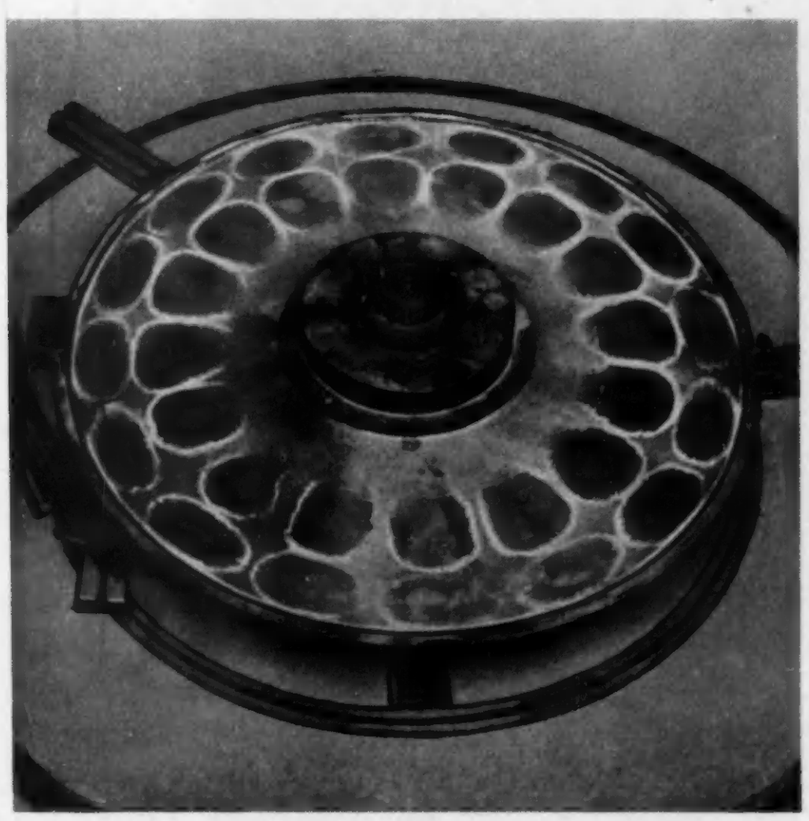

Fig. 4.—Eight nodal diameters and two nodal circles.

produce, when superposed, the "standing wave"

$$y = 2\,a \cos n\,\theta \cos p\,t \quad . \quad . \quad (2)$$

It will be seen that equation (2) represents the stationary vibration described above, where y is the deflection at time t at the angular position θ, n is the number of nodal diameters, and f is the frequency of vibration, where $p = 2\pi f$.

The term "standing wave" therefore will be used to denote such a vibration in a rotating wheel, and the above analysis shows that it may be alternatively regarded as two travelling waves, viz., a backward wave represented by equation (1*a*) and a forward wave by (1*b*).

When the velocity of the backward wave is equal to the angular velocity of the wheel, the wave becomes stationary in space, and the vibration, as viewed by a stationary observer, would appear as a permanent deformation. Analytically, this may be expressed thus:—

If θ be the angular position in space, and ω ($= 2\pi R$) the angular velocity of the wheel, the

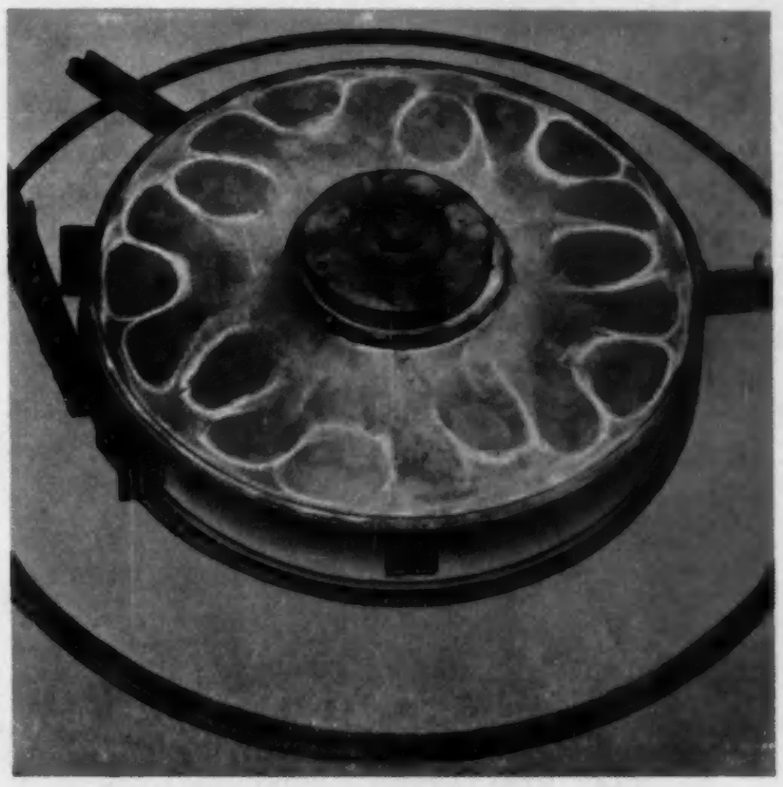

Fig. 5.—Complex vibration pattern.

equations (1*a*) and (1*b*) become

$$y = a \cos \{n\,(\theta - \omega t) + p\,t\}$$
$$= a \cos \{n\,\theta + 2\,\pi\,t\,(f - n\,R)\} \quad . \quad (3a)$$

and

$$y = a \cos \{n\,\theta - 2\,\pi\,t\,(f + n\,R)\} \quad . \quad (3b)$$

If the angular velocity $\frac{p}{n}$ of the backward wave equals the angular velocity ω of the wheel,

$$p = n\,\omega$$

therefore

$$f = n\,R \quad . \quad . \quad . \quad (4)$$

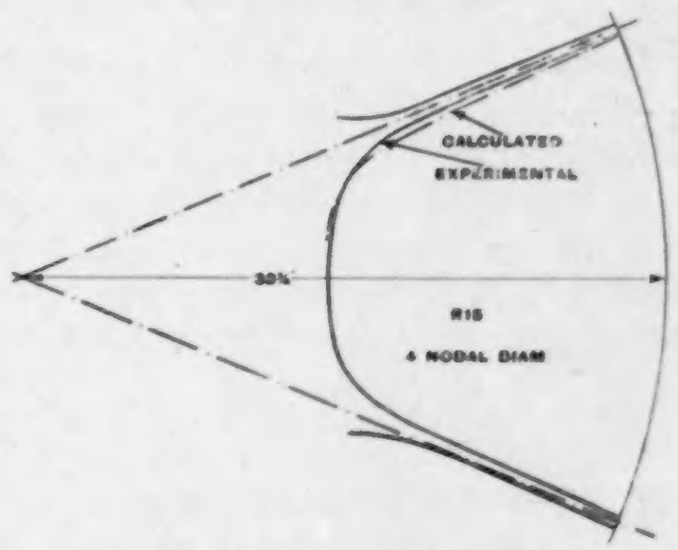

Fig. 6.—Calculated and experimental curves.

and equation (3*a*) becomes

$$y = a \cos n\,\theta \quad . \quad . \quad (5)$$

It will be seen that this represents the condition described above, which, for want of a better term, will be called a "stationary wave."

Any speed for which equation (4) holds represents a critical condition, since an isolated force, such as a jet of steam acting on the periphery of the wheel, may cause a stationary wave of large amplitude to be built up and maintained.

For any given wheel there is a range of critical speeds, corresponding to different numbers of nodal diameters, and it is found that the amplitudes are largest for fewest nodal diameters.

From what has been said it might be expected that it would be possible to prognosticate from the static test what the critical speeds would be. The static test, however, indicates frequencies of the

Fig. 7.—Static tester in vibration laboratory.

elastic vibrations only of the wheel ; superposed on this are the effects of centrifugal force and temperature. The effect of centrifugal force is important, as it stiffens the wheel and thus raises its natural frequencies. If f_0 be the frequency when stationary, and f the frequency at speed R, a relation of the form.

$$f = \phi(f_0, R) \quad . \quad . \quad . \quad . \quad (6)$$

must hold.

The appoximate relation

$$f^2 = f_0^2 + KR^2$$

has been investigated and is found to be unreliable for design purposes, as K depends on the characteristics of the wheel itself and on the number of nodal diameters, and it even appears to alter with the speed.

The Effects of Vibration.

The effects of wave motion in the wheel are threefold, and in order of importance are as follows :

(1) It may happen that the vibration is of such a character that the stresses in the disc itself exceed the estimated value and in time the wheel bursts. Fortunately, such cases are now exceedingly rare, although many accidents have been attributed to this cause.

(2) Wheels may not actually burst, but the amplitude of vibration may be such as to cause rubbing of the disc on the diaphragm. The rubbing sometimes provides a clue to the mode of vibration ; for example, a two-nodal diameter vibration may show two places, 180 deg. apart, where rubbing has occurred.

(3) The vibration may cause failure of the blade by fatigue.

This trouble may not develop until some time after the turbine has been in operation, and it is difficult to forecast the effects, as fatigue and the phenomena attaching thereto are not yet fully understood.

General.

Historically, it is believed that the conception of travelling waves in rotating discs originated in deflections observed in circular saws, and troubles associated therewith. Be that as it may, it is certain that travelling waves do exist in turbine wheels, and they may be the cause of serious trouble if they are not fully understood and, if necessary, eliminated. It is necessary to appreciate that the possibility of waves and their

associated phenomena being present is not always dependent on the presence of suitable external exciting forces of a frequency likely to cause resonance. Vibrations can arise from causes inherent in the plant itself. The way to safety lies, therefore, in arranging matters so that, with a knowledge of the periodicities at which vibrations are likely to occur, the wheel is manufactured to avoid synchronous excitations, critical speeds, and sympathetic resonances.

This can be effectively accomplished, at the moment, only by experiment, and with plant which is both expensive and elaborate. Whether or not the day will come when mathematical prediction will enable the designer to estimate with accuracy the resonant performance of wheels is not known with certainty. The problem is one of great complexity, and has taxed the brains of many accomplished mathematicians. At present, the only methods of design available are those which depend largely on graphical analysis, usually of a "trial and error" character, and are therefore lengthy and cumbersome. In any event, analysis to be acceptable to the designer must be amply proven by experiment, and this is itself a lengthy process.

The first experiments on turbine wheels were carried out by Stodola,* and these confirmed what had been suspected by him, namely, that critical speeds depending solely on the characteristics of the wheel could and did exist. These early experiments were amplified and their scope enlarged by Campbell,† of Schenectady and others.

The General Electric Company, Ltd., of England have felt for some years that with the increase in size and capacity of turbine plant it was incumbent on them to present a finished product which was, as far as scientific research and engineering knowledge could make it, free from all possible trouble. To this end, as unknown vibrations are a potential source of trouble, it was decided to equip a vibration laboratory at Fraser and Chalmers' Engineering Works, Erith, Kent.

Description of Plant.

As the plant is probably unique in many respects, it may not be out of place to describe it briefly.

In fig. 7, a view of the laboratory from the entrance is given. In the foreground is the static tester, on which is mounted a bladed turbine wheel. This tester is a cast-iron block, 14 tons in weight, set in 30 tons of concrete, this mass being necessary to prevent, as far as possible, vibration of the supports. On this tester the sand pictures of figs. 1 to 5 were obtained, but the data obtained from the static tester are not at present adequate to enable the critical speeds to be predicted with certainty, and it is not now used to any great extent.

On the right of fig. 7 is the blade tester, designed to hold any size of blade manufactured. This tester, also, is of considerable mass, and is on a concrete foundation to absorb vibrations as much as possible. One or more blades connected to a cover-band section can be accommodated, and tests are made to ascertain the effect of the cover-band on the natural period of the blades.

This blade tester can be employed for an exhaustive series of tests to determine for each type of blade the following vibration characteristics :—

(1) The natural frequency in the two principal planes, in the gravest mode.

(2) The same in as many different modes of vibration as possible.

(3) With several blades clamped by a cover-band.

(4) A number of identical blades will be tested to ascertain the effect of the tolerances of manufacture.

The chief item of plant is the dynamic tester, which is to be seen in the foreground of fig. 8. It is accommodated in a concrete and asphalt-lined pit about 15ft. square and 17ft. deep.

The principal desiderata in the design of a dynamic tester are: (1) ease of speed control; (2) good insulation for the electrical circuits; (3) quickness of operation in the tests, combined with accuracy of results; (4) as far as possible, a duplication of the running conditions in the actual turbine.

So far as the authors are aware, every other plant in existence at the present time employs steam to rotate the wheels under test, and consideration was paid in the design of the present tester to the relative merits of steam and electric drives. It might at first be thought that the obvious method was to employ steam to drive the wheel under test, using the test wheel as a driving unit, but this would not have permitted unbladed wheels to be tested; an external drive was therefore essential. A turbine might have been used, in which case the wheel could have been cooled by exhaust steam; but an electric drive was preferred, the wheel running in a vacuum in order to prevent overheating due to the fan action of the blades. This, obviously, provided the best solution to items (1) and (2) above, and the electric motor, which can be used as a brake, has the additional advantage of being able to regenerate back to the line. The provision of a Ward-Leonard control also gives an excellent speed adjustment to within fine limits. Another advantage of using an evacuated chamber is that, by the partial admission of air, any desired temperature difference can be obtained between the blades and the hub, to simulate working conditions. The problem of maintaining a sufficiently good vacuum was carefully considered,

* *Schweiz. Bauzeitung*, 1914.

† Campbell, *General Electric Review*, 1924, page 352. *Brown Boveri Review*, December, 1923, Page 230; Freudenreich, ENGINEERING, vol. cxix, pages 2 and 31 (1925). Oehler, *Zeitschrift des Vereins deutscher Ingenieure*, 1925, page 335; Hort, *Zeitschrift des Vereins deutscher Ingenieure*, 1926, page 1375; Collingham, *The Engineer*, 1931, page 402.

as sound design and manufacture are essential for the success of the plant. So far as the authors are aware, the evacuation of a chamber of this type, including a comparatively large rotating shaft, has not previously been attempted. As a result of careful design and excellent manufacture this has proved completely successful, and it is possible in a short space of time to attain an absolute pressure of 0.17 mm. mercury in the casing, which has a volume of about 400 cub. ft. The vacuum pumps installed are shown on the right of fig. 8.

Fig. 8.—Dynamic tester in vibration laboratory.

It would not be wise at this stage of the investigation to state didactically that the drive *in vacuo* is better than in steam, as there is still the effect of the atmosphere on the shape of the resonance curve (which is considered below) to be investigated. Up till the present, however, there is no evidence to warrant a change in the method of test, and, as is explained later, such evidence as is available tends to favour running *in vacuo*.

Fig. 8 shows the casing, the top half of which is partly visible resting on three concrete beams which are provided to cover the pit completely, thus minimising the consequences of an accident. These beams weigh 9 tons each, and the casing, which is of oval section, is of cast iron 3 in. thick. The bottom half, weighing 30 tons, rests on two brackets on concrete foundations. The shaft inside the casing, which carries the wheel, rotates in two roller bearings fitted on gimbals, to allow for the distortion of the casing under vacuum. On this shaft there are 12 terminals which are electrically connected through the shaft to slip-rings outside the casing. A two-speed gear enables a wide range of speeds to be obtained.

As the wheel is running *in vacuo*, there is no difficulty with electrical insulation, and no special precautions are needed on this account.

In fig. 8, behind the static tester, can be seen the variable-frequency alternator, with its Ward-Leonard control. This has a wide range of frequencies, and is used in conjunction with electromagnets for exciting vibrations in blades or wheels. A 12½-ton overhead crane, electrically operated, is provided for handling wheels and parts of the equipment.

In the background of fig. 7 can be seen the entrance to the laboratory office where records are measured and stored, and on the left of the office is the dark room, which is also employed as the control room of the laboratory. This room contains the amplifiers and oscillograph described later.

Description of Measuring Apparatus.

As the fundamental quantity in all of these experiments is time, it is of the highest importance that the measurement of time shall be beyond suspicion. To ensure accuracy on this count, therefore, the basic standard at the laboratory is a 500-cycle tuning fork, which is plucked in a standard manner, and which has been calibrated in that way by the National Physical Laboratory. The sub-standard in everyday use is a valve-maintained 50-cycle tuning fork, which is frequently checked with the standard.

Measurement of the vibrations of stationary wheels or blades can be effected directly by means of a vibration recorder. This consists of a lens system for reflecting a spot of light from an arc lamp to a revolving camera by means of a mirror fixed on the vibrating body. Another spot of light is reflected to the camera by a mirror on the tuning fork, thus providing a time scale on the record. This method of measurement has the advantage of being direct, but it is somewhat tedious in actual use, owing to the requisite adjustments to the optical system. Electrical methods are more convenient, and two alternative arrangements are now used. One of these employs the change in electrostatic capacity between the vibrating member and a small metal plate, and the other consists of an electromagnetic coil placed opposite the

vibrating member. In either case, a suitable valve amplifier magnifies the oscillations so that they can be recorded by an oscillograph. The electromagnetic-coil system is simpler to use, but the capacity method has the advantage of giving an undistorted record of the vibration of the wheel, since the former registers the velocity of the vibrating member, whilst the latter registers its displacement.

The next measurement which is required is that of speed. As there was no sufficiently accurate speed indicator available, it was necessary to design and manufacture one. This was accomplished by fixing on to the shaft a chromium-plated optical commutator, which, developed into a straight line, is as shown in fig. 9.

The shaded portions are chromium plated, and the leading edges 60 deg. apart. A spot of light is projected on to this commutator, either on to the section *A*, *B* or *C*. It is reflected back on to a photo-electric cell, the current from which is amplified by a two-valve amplifier, and then passed through a loop of the oscillograph. By choosing the appropriate section on the ring it is possible to cater for different speeds, by arranging to record one three, or six segments per revolution; and by considering the width of the segments it is possible to correlate the vibration on the record with the angular position of the wheel. The type of record obtained can be seen in fig. 10.

Another factor in the accuracy of these tests is the difficulty of reproducing a vibration with certainty when it is excited by an applied periodic force. A forced vibration exists over a range of frequencies having a maximum value at one frequency only. In other words, for each type of vibration there is a resonance curve, the characteristics of which are determined by the damping of the vibration. To obtain reproducible results of natural frequency, it is necessary to ensure that, at the instant of taking the record, the amplitude of vibration is at its maximum value, in which case the frequency of vibration is the true natural frequency. The resonance curve is also of interest, as the natural period is slightly altered by the damping, and an investigation has therefore been undertaken to consider this feature.

Tests Undertaken.

The importance of a series of tests on turbine wheels cannot be over estimated. The possibility of danger to life and interruption of the supply of the modern super power station are such as to warrant every human effort to avoid such troubles.

It is vital, therefore, to plan the tests so that, firstly, all possible sources of error are eliminated; and, secondly, practical conditions are closely imitated and erroneous conclusions avoided. These considerations led the laboratories to proceed along two lines of investigation, viz., experimental and theoretical. Thus the initial experiments consisted of an investigation to determine the accuracy of purely theoretical relations.

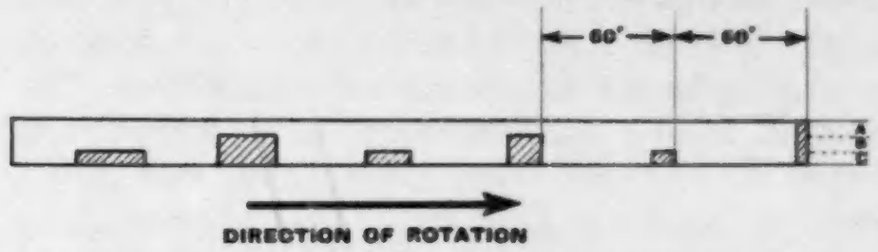

Fig. 9.—Development of optical commutator.

The next point of importance to bear in mind in conducting a series of tests is the imitation of the practical conditions of running and to consider the actual forces at work in a turbine, as compared with those in the tester. In the tester, vibrations are always excited by one or more electro-magnets, employing alternating current of variable frequency for ordinary vibrations, and direct current only for the production of stationary waves. In a turbine, however, the force on the wheel is presumably uniform around the periphery of the wheel, with the possible exception of the diaphragm joint; hence the conditions in practice are not identical with those in the tester. Secondly, there may be impulses in the steam flow which may cause individual blades to vibrate; also the diaphragm may vibrate, &c. The wheel tester, however, has this advantage, namely, that, with the employment of current of a variable frequency in the exciting electro-magnets placed opposite the wheel during rotation, it is probable that all the possible vibrations of the wheel itself are produced, and thus will be known and can be avoided. Vibration due to other external causes, however, must be investigated independently.

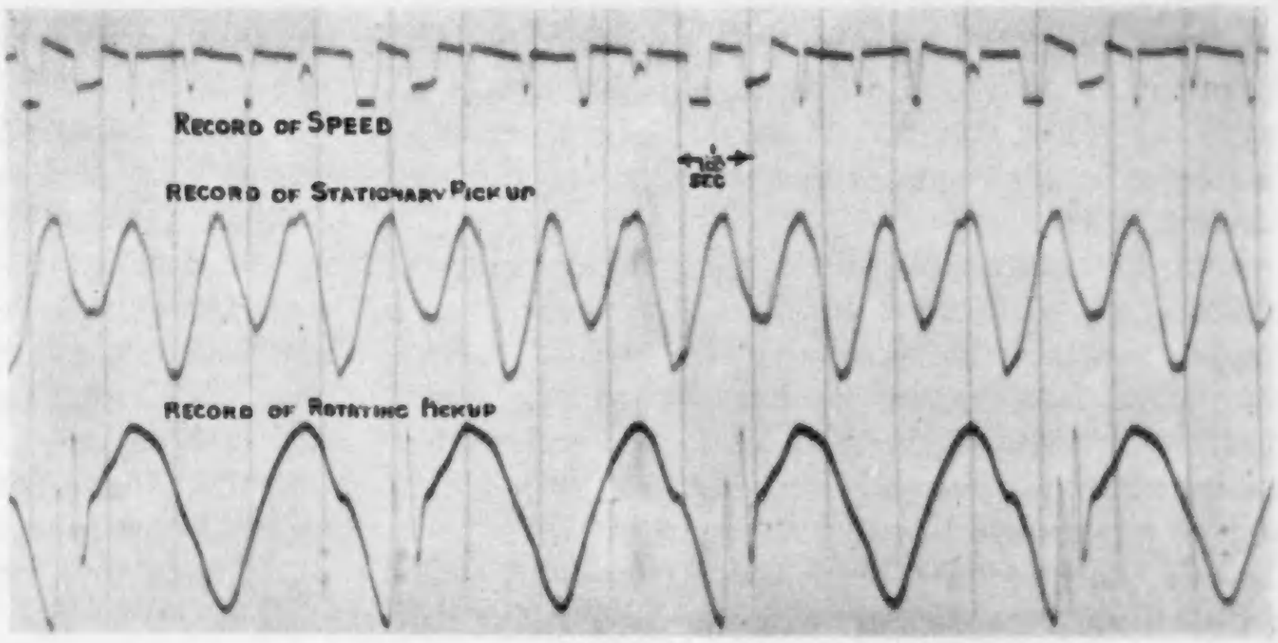

Fig. 10.—Typical oscillogram record obtained.

With these points in mind, the programme of tests referred to below was undertaken.

Vibration tests in turbines can be divided into three main groups, viz., those on the vibrations of blades, those on the vibrations of stationary wheels, and those on the vibrations of rotating wheels.

Blade Vibrations.

From the fundamental theory of sound, a standard formula is known for the natural frequency of a bar clamped at one end and vibrating in a transverse direction, and the first experiments undertaken were to ascertain how far this theory could be verified. In every case it was discovered that the periodicity was about 3 per cent. below the calculated value, and it is considered that the discrepancy is due to the impossibility of obtaining a mathematically rigid fixation.

The next test was on a complete set of blades for a turbine wheel; 400 blades in all were tested and a

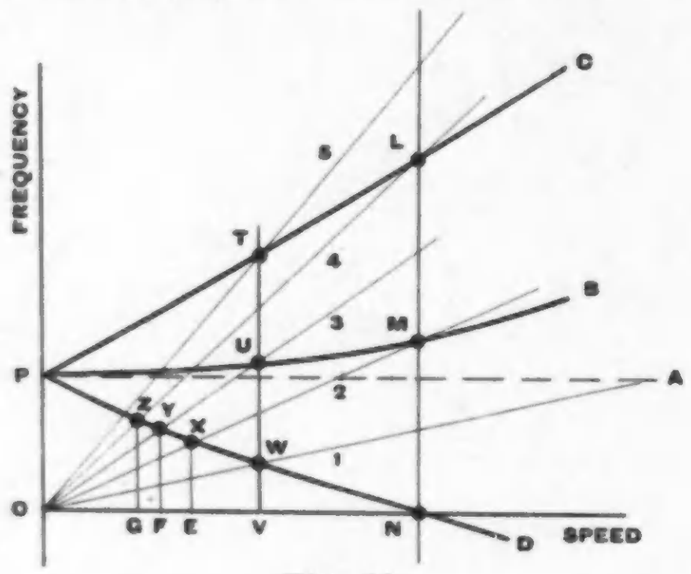

Fig. 11.

statistical analysis was undertaken of the variations due to the idiosyncrasies of individual blades. Statistical information was then obtained of the minimum number of blades it is necessary to test in order to arrive at an average value within a given margin of the true mean. This test resulted in a considerable economy in time in testing further batches of blades.

Finally, tests on blades are being carried out, as indicated above, to show the effect of the cover-band control, and also the fixation in the wheel. Since the natural frequency of light square bars is 3 per cent. below the calculated value, then the percentage difference in the case of heavy blades in the tester may be expected to be greater than 3 per cent.; also the effect of fixation of the blades in the wheel will still further increase the difference. Lastly, the effect of the cover-band will again affect the result.

Static Test on Wheels.

As stated above, the static tester is not often employed, but the values of the natural frequencies of vibration of the stationary wheel are obtained with the wheel on the shaft in the dynamic tester. Tests were, however, initially undertaken to determine the effect of fixation, and it has been shown that, for any mode of vibration with more than one nodal diameter, the difference is almost negligible. For the one nodal diameter vibration, however, fixation plays a large part, as will be seen later.

Tests on Rotating Wheels.

The somewhat complicated data obtained from the rotating or "dynamic" test are best understood by means of the diagram, fig. 11, devised by Campbell. On this diagram, ordinates represent frequencies of vibration, and abscissæ represent speeds of the wheel. Thus OP represents f_0, the frequency of vibration of the stationary wheel for a particular number of nodal diameters. If centrifugal force were absent, this frequency would be constant at all speeds, and could be represented by the dotted line PA. The stiffening effect of centrifugal force, however, causes the frequency to increase with speed, giving the curve $PUMB$. On reference to equations (3*a*) and (3*b*), it will be seen that the frequencies of the travelling waves referred to axes fixed in space are $f + nR$ and $f - nR$. On the diagram, OV represents a speed R; VU the corresponding frequency of vibration f; $VT(= f + nR)$ and VW $(= f - nR)$ the frequencies of the forward and backward travelling waves, respectively.

As the speed increases, the frequency of the forward wave, given by the curve $PTLC$, always increases, but the frequency of the backward wave decreases as shown by the curve $PWND$, becoming zero at the point N. Thus ON is the critical speed for this number of nodal diameters, and the backward wave is a stationary wave. This is the condition given by equation (4).

In addition to this "major critical speed," there is a series of "minor critical speeds." These are speeds for which the frequency of the backward wave is an integral number of times the speed of the wheel.

Thus the equation $f - nR = mR$ gives the mth minor critical speed, where $m = 1, 2, 3,$ &c.

The inclined lines in fig. 11 radiating from the origin, are the lines $f = R$, $f = 2R$, $f = 3R$, &c., so that a point where the backward-wave curve cuts one of the lines gives the condition for a minor critical. Thus, the point of intersection W gives the first minor critical, for which the speed is OV and OE, OF, and OG, are other minor critical speeds, given by the intersections X, Y and Z.

The data for the diagram are obtained as follows: The wheel is run at the required speed, and vibrations are excited in it by means of the electromagnet carrying alternating current of variable frequency. The applied frequency may be either that of the forward wave, $f + nR$, or of the backward wave, $f - nR$. It is generally found that one of these produces vibrations more readily than the other. A stationary wave may be produced by using current of zero frequency, that is, direct current. Two

recording pick-ups are employed, of either of the types described above. These are placed opposite the rim of the wheel; one of them is stationary, and the other is fixed to a specially rigid disc mounted on the same shaft as the wheel under test, so that it rotates at the same speed.

The frequencies recorded by these pick-ups may be understood by reference to fig. 11. *VU* is the frequency of the vibration recorded by the rotating pick-up, and the stationary pick-ups record the frequencies *VT* and *VW*. Generally, however, only one of these latter frequencies is conspicuous, namely, the higher one *VT*, and, therefore, in order to determine the number of nodal diameters, it is necessary to measure the frequency given by the rotating pick-up as well.

Thus,

$$VT = f + n\,R$$
$$VU = f$$

R is obtainable from the speed record, so that *n* can be determined. A check on the accuracy of the measurement is obtained from the fact that *n* must be an integer.

In fig. 11 one mode of vibration only is shown—namely, two nodal diameters. The complete diagram for any wheel includes all the modes measurable.

Fig. 10 shows a typical oscillogram obtained in such a test. The transverse lines are recorded by the time-marker, and represent hundredths of a second. The first record gives the speed, the second is the record of the stationary pick-up, and the third that of the rotating pick-up.

It will be observed that, on the record from the rotating pick-up, a discontinuity occurs at regular intervals of one per revolution. The cause of these disturbances is the passage of the rotating coil past the exciting magnet.

It is interesting to note, in passing, that it is probable that the one nodal diameter major critical speed cannot exist, and it is certainly outside practical running speeds for all wheels. For this mode of vibration, however, minor criticals have been investigated with interesting results. It will be seen that the frequency of the force required to maintain the first minor critical vibration, for instance, for this mode, is one impulse per revolution, and is therefore equivalent to that produced by dynamic unbalance. Further, the fixation of the wheel on the shaft, which has little effect on other modes, is found to have a large influence, which it is not easy to forecast, on the one nodal-diameter vibration and its minor critical speeds.

It will be seen from the foregoing that in a turbine, conditions do exist which may give rise to critical vibration. For example, the force on the wheel due to the steam is equivalent to a continuous pressure around the periphery, but at the diaphragm joint there may be a discontinuity in the pressure, the net effect of which is that of a resultant force at each diaphragm joint.

Sympathetic vibration may also be set up in the shaft, due to out-of-balance rotational forces and the like. It is, therefore, apparent that the only safe course is to obtain an intimate knowledge of all the critical speeds at which wheel vibration can occur, and so to design the wheels that there is, in all cases, a safe margin between the criticals and the running speed.

Results of Tests.

This article would not be complete, neither would it carry the weight of experimental evidence, if

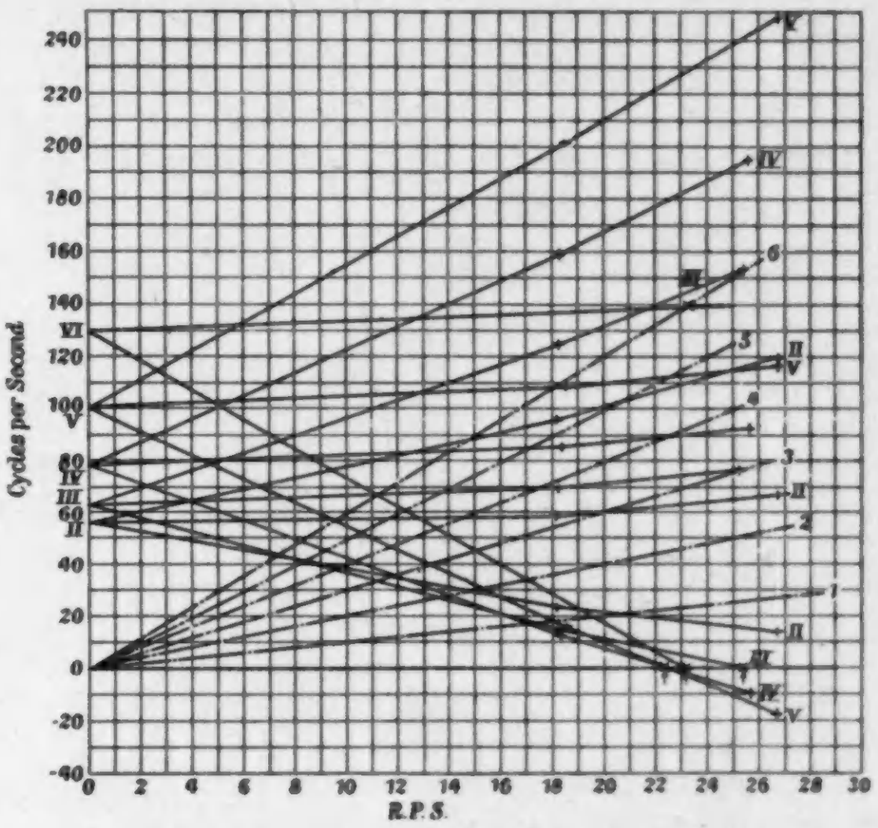

Fig. 12.—Characteristics of 1,500 r.p.m. turbine wheel, 9 ft. diameter, 21 in. bore.

TABLE I.

Nodal Diameters.	Major Critical Speed in R.P.S.
3	25.35
4	22.38
5	22.4
6	23.2

actual test results were not given. Evidence, however, to be of use to the designer, takes a considerable time to collect, as one isolated result is of little value in predicting the effect of a change.

Consider an actual case of a large wheel for a turbine running at 1,500 r.p.m: the wheel is 9ft. in overall diameter and has a bore of 21in. The curves of fig. 12, are the characteristics of such a wheel, and in Table I the critical speeds are given as obtained.

Obviously the three nodal diameter critical, which is practically at the running speed of 25 r.p.s., had to be altered. The wheel was therefore tuned by turning off 10 per cent. of the thickness over the profile, and again tested. It will be seen that a

general reduction in the values of the critical speeds was effected by tuning, the percentage being greater for the lower nodal diameters. This would be expected, as the wheel was uniformly reduced over its surface. By turning off unequal amounts it is possible to produce a large change in the critical speeds of the higher or lower numbers of nodal diameters, as desired.

The characteristics of the wheel after tuning are shown in fig. 13 and in Table II.

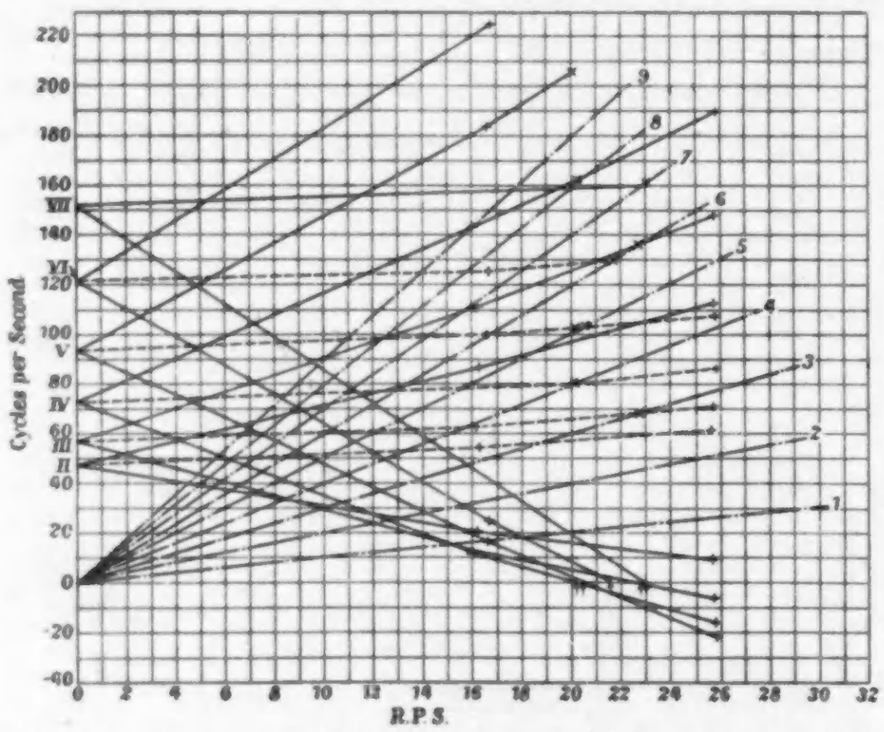

Fig. 13.—Characteristics of same wheel after tuning.

TABLE II.

Nodal Diameters.	Major Critical Speeds in R.P.S.		Per Cent Reduction.
	Before Tuning.	After Tuning.	
3	25.35	22.75	10.3
4	22.38	20.19	9.8
5	22.4	20.5	8.5
6	23.2	21.6	6.9

These tests were all made on the dynamic tester in the laboratory, and the question arises how far they represent the frequencies of vibration in an actual turbine. An experiment has been made to obtain information on this point, and a turbine of 30,000 kW capacity at the Hams Hall power station of Birmingham Corporation, which was put at the disposal of the Reserach Laboratories by the kind permission of the City Electrical Engineer, Mr. F. Forrest, was equipped for this purpose. Coils were embedded in the diaphragms opposite the discs, and pick-ups were fixed opposite the cover-bands. This was done for four of the six last wheels in the low-pressure side of the turbine. Critical speeds were expected during the running up to speed of the turbine, and an oscillogram was therefore taken at every point where a vibration was visible. Of the exposures taken, some gave minor criticals, and two were obtained which undoubtedly represented a major critical vibration.

In the wheel under consideration, the critical speed of the two nodal-diameter vibration occurred in the dynamic tester at 21.3 r.p.s., corresponding to a forward wave frequency of four cycles per revolution, or 85.2 cycles per sec. This had been obtained in the tester with a direct-current exciting magnet. In the two records on the actual turbine, vibrations were obtained at 21.38 r.p.s. and 21.6 r.p.s., respectively, and, further, each had a forward wave frequency of four cycles per revolution. This is *prima facie* evidence of a two nodal-diameter vibration, and provides a remarkably close check on the results given by the dynamic tester. Naturally, extreme conditions of temperature difference do not exist during running up to speed, as there is no load on the alternator. The final test, therefore, was to run the turbine on load for some time and at over-speed, and, as was expected, no critical vibration could be obtained. It is not claimed that the dynamic tester gives an exact reproduction of running conditions, but the above experiments on site indicate that the agreement is sufficiently close for design purposes; and up to the present time it represents all that can be done to enable the designer to eliminate dangerous critical vibrations. As the tests progress and knowledge of the art increases, there is no doubt that a closer approximation to the actual conditions will be obtained. It is considered, however, that this initial experiment carries sufficient weight to be given to the public, as, so far as the authors are aware, it represents the first public contribution on the subject where confirmation, even though only at one point, between experiment and practice has been attained.

In conclusion, the authors wish to express their appreciation of the work of their colleagues, Mr. A. F. Cornock and Mr. A. J. Till, and for their untiring collaboration in the conduct of these tests, and in the evolution of the plant.

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